Cellular IoT Devices 2018

Abstract: This document provides technical and cost comparisons for 2G, 3G, 4G, and anticipated 5G IoT devices, as well as a thorough review of existing cellular IoT business as it shifts from GSM/GPRS to LTE-M and NB-IoT. Market share, shipment, pricing, and revenue data are included with a five-year forecast for growth in key areas.

January 2018

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MEXP-C-IOT-18
January 2018

1 EXECUTIVE SUMMARY

The Cellular IoT market is starting its dramatic transition from M2M to IoT. In other words, instead of the legacy formats that simply re-use technology intended for phones, new formats and new products are now optimized for longer battery life, lower cost, and longterm operation.

The transition will require about 3 years to make a significant impact on revenue for suppliers. As applications shift from GPRS or LTE Cat-4 to Cat-M or NB-IoT, the dollar value of the device, module, or chip will typically drop. So, we are currently waiting for the volume of new applications enabled by long battery life, to see an impact in product revenue in this market.

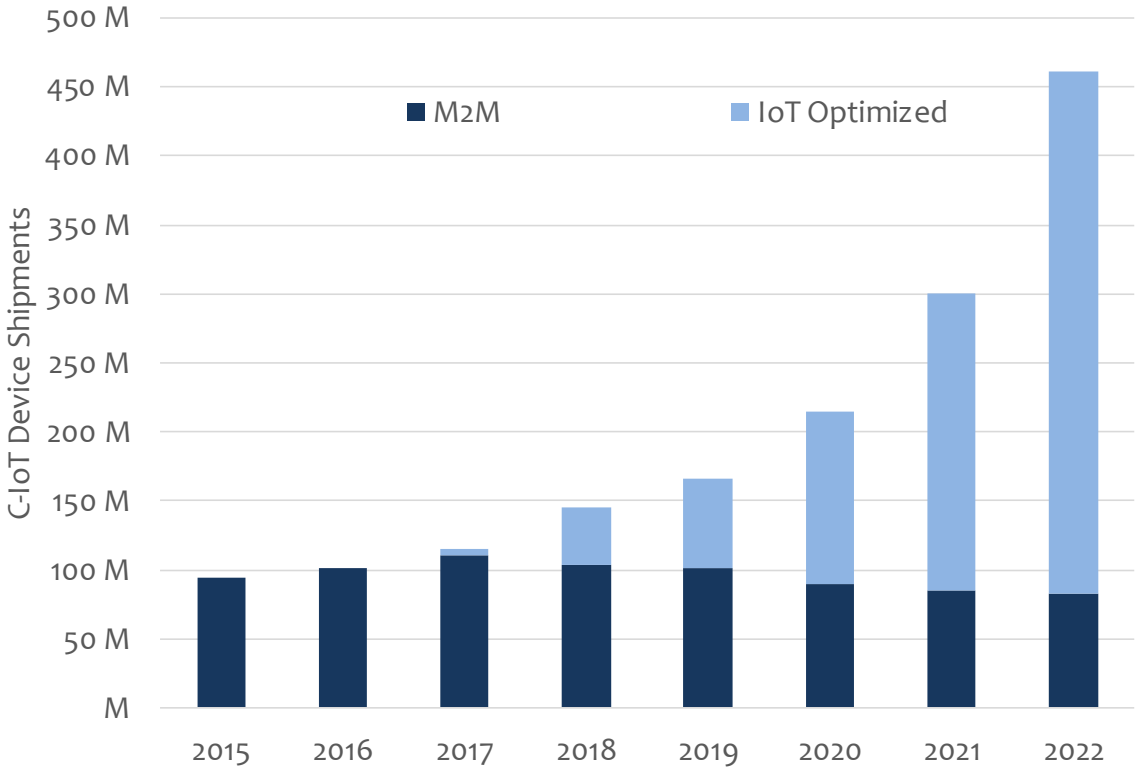

Chart 1: Transition from M2M to Cellular IoT Device Shipments, 2015-2022

Source: Mobile Experts

Note: M2M includes 2G, 3G, and LTE through LTE Cat-1. "IoT Optimized" includes LTE-M, NB-IoT and 5G IoT

C-IoT is a story of new applications sprouting after new technology makes useful things possible. Until recently, water meters or bicycles were difficult to connect, or needed frequent battery changes. The extended range and long battery life of new standards makes these business models viable.

Growth in this market will be rapid at multiple layers of the market. Specifically,

- IoT Service Revenue will grow by 21% CAGR through 2022, with low pricing offsetting the rise in volume for mobile operators.
- IoT Device shipments will grow by a CAGR of 32% through 2022. This number is deceiving since 2G, 3G, and many LTE formats will shrink while Cat-M and NB-IoT will grow at >100% CAGR.
- IoT Module revenue will grow at 20% CAGR through 2022.
- IoT Semiconductor revenue will grow at 18% CAGR as well.

Notably, the hype surrounding 5G IoT devices does not appear justified through the 2022 timeframe. Our forecast includes a healthy adoption rate for 5G NR in IoT applications (similar to successful entries such as LoRa), but during the next five years this means that 5G shipments will reach only about 1 million units per year.

2 MARKET DRIVERS FOR C-IOT

In the big picture, the IoT market is the next step in the automation of the world. We have automated simple things locally for many years (thermostats with simple mechanical switches or timers). At its essence, the IoT is about automating thousands of device types so that people don't have to do many simple tasks.

COMPUTING PLATFORMS ARE CHANGING

Computing was viewed in the 1970s through 1990s as the automation of the office. Technology moved from mainframe (centralized) computing to highly distributed and personal computing by 2010. The trajectory was pretty clear through the early days of smartphones, where the trend was to move away from centralized computing. Connectivity from 1960 to 2005 was not adequate to consider any distribution of the computing function between a centralized location and thousands of remote users.

But as connectivity becomes cheap enough and fast enough, it's not necessary to have all of the computing on the local platform anymore. The early recognition of this is seen in database applications for office mobilization such as Salesforce, or LinkedIN. Social media platforms and any other cloud information service has already latched onto this concept. So, today the paradigm is Cloud Computing.

What's the next step? Cars are taking on a huge level of local computing power, to make instant and highly reliable decisions on safety issues. Similar automated platforms are now seen on trains, cranes, drilling equipment, manufacturing lines, and many other places. Edge computing, in this way, will become a major part of information analysis in automated things. Many other devices (such as drones) may want to send video back to the cloud for image processing such as facial recognition, so that huge storage databases and faster computing platforms can be accessed.

These highly distributed computing platforms (where both edge computing and cloud computing are used as needed) rely on a low-latency connection. LTE is getting close, with latency in the range of 20-30 ms. However, to be efficient the latency of a 5G network will be highly desirable for more advanced hybrid computing platforms.

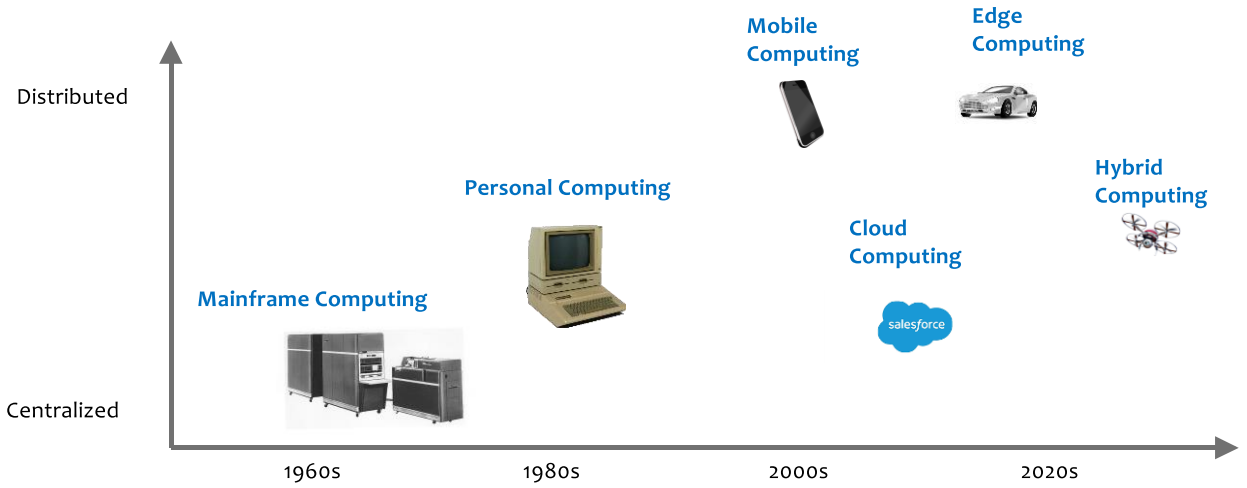

Figure 1 Evolution of Computing: Centralized to Distributed and now Hybrid Computing

Source: Mobile Experts

ENTERPRISES ARE PULLING THE IOT MARKET

You may notice that all of the examples we cited (drones delivering packages, automated cranes, manufacturing equipment) are enterprise applications. Generally speaking, consumers are not driving the need for wide-area IoT devices as urgently as enterprises are. Yes, there are bicycle tracking applications and dog-collar tracking products. But the high-dollar drivers of the market are the high-performance devices that require high bandwidth and will tolerate high cost levels.

In particular, applications that require tracking sensor data over widespread areas, or for moving objects, needs IoT connectivity to enable the basic automation. Examples include:

- Automation of basic oil well monitoring such as pressure, temperature, and the level of crude oil in a tank. Simple sensors can eliminate hours of technician time to drive around the oil field.
- A building that is outfitted with security sensors on the doors and windows can reduce security staff dramatically.
- Smart "trash cans" that notify technicians when they're full can improve efficiency in waste operations.
- Warehouses don't need to be shut down with workers physically counting every item in inventory, if inventory accuracy is high enough.

There are many other examples, but the common theme is that IoT sensors can eliminate wasted time for employees by reducing the time spent on "go over there and check". We call this "Information Automation".

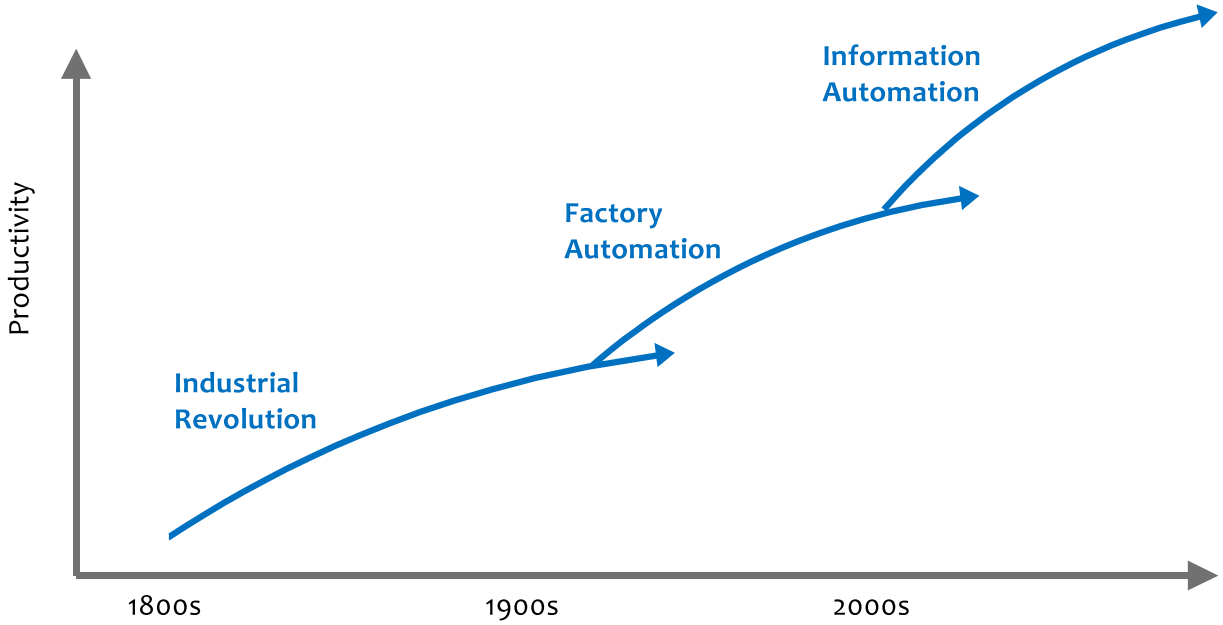

Figure 2 Automation of Information: The next step in productivity

Source: Mobile Experts

Enterprise IoT applications can save costs, but they can also enhance productivity. Drones can, in some places, deliver more packages per hour than a human driver, because traffic is simply not a factor. Wineries can control the stress on grapes with better real-time moisture sensors to produce better wine in larger quantity. Predictive maintenance can eliminate downtime for higher productivity.

Overall, enterprises have two reasons to invest in IoT: Reduced costs and higher productivity.

OPERATORS ARE PUSHING THE IOT MARKET

For 30 years, the mobile telecom market has grown by selling more phones and increasing the ARPU (average revenue per phone user). However, today almost everyone in the world that can pay for a phone already has one, and the ARPU is dropping in many key countries. How can the operators keep growing their service revenues?

There are two major thrusts in play right now.

- Some operators, notably in the USA, are considering strategic moves into the entertainment market, gaining exclusive access to video content so that they can both create and distribute the video content. Vertical integration on a new scale.

- Almost all operators worldwide are looking to the IoT as a new source of service revenue. Claims of "50 billion devices" (now 20 billion devices) have hyped the industry up so that operators believe the potential revenue stream could be in the hundreds of billions of dollars, comparable to the trillion-dollar smartphone business.

Looking more closely at the IoT market and its growth, it's possible that it could reach "hundreds of billions of dollars" someday, but we anticipate a total wide-area service opportunity in the range of 80 billion dollars in 2022.

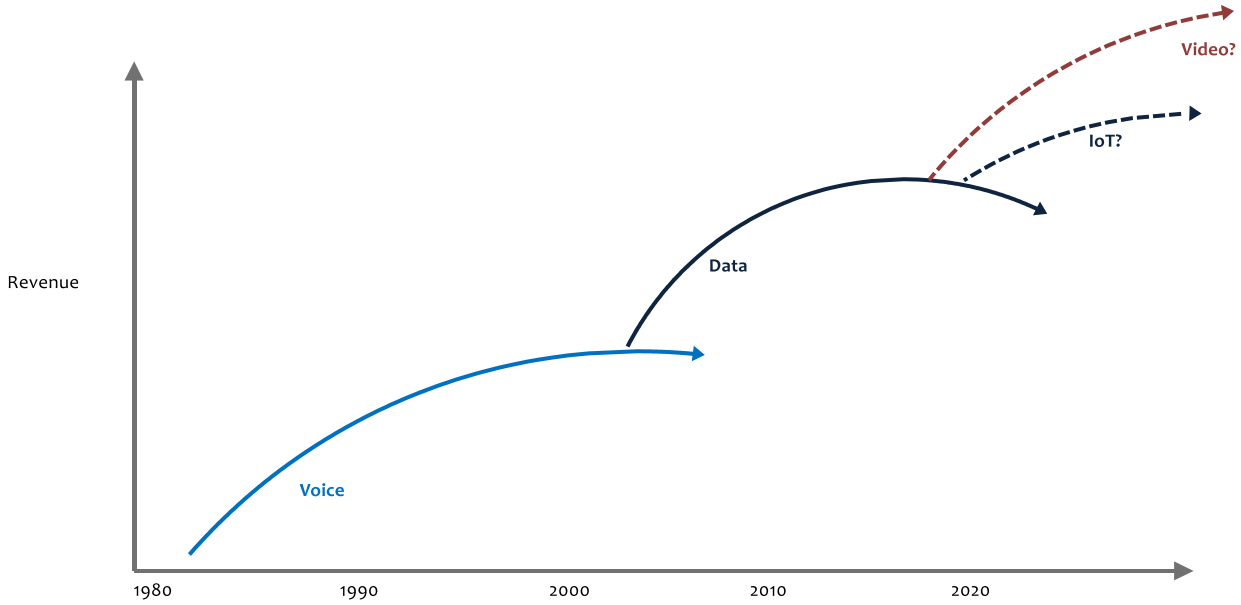

Figure 3 Revenue Growth for Mobile Operators: Showing what comes next

Source: Mobile Experts

Most operators that are pushing IoT capabilities have very little talent when it comes to selling to enterprises. AT&T and Vodafone know how to sell data plans to consumers, but they don't know how to sell bursty data services to an enterprise. This mismatch makes it very difficult for the operators to create an IoT revenue stream in Western markets.

China is different. Recently, the Ministry of Industry and Information Technology (MIIT) in China has applied pressure on the three state-owned operators. China Telecom, in particular, has moved very quickly to deploy a NB-IoT network and they have successfully pushed bicycle-sharing companies to invest heavily in a network of bicycles for the network. As of December 2017, we estimate that China Telecom has roughly 8 million bicycles on their NB-IoT network because of the strong endorsement of the government for this single technology. While the "technology push" market model simply doesn't work in Western countries, we believe that it's working in China due to the top-down structure of the economy.

Because the government can direct all three mobile operators to invest billions of dollars, there is certainty that the network will be deployed, and that the service will be available for years to come. This gives the application development vendors the certainty that they need to invest heavily in a risky business plan. We expect to see this play out in the asset tracking market, as well as some areas of the automotive market where government policy can be used to require IoT connectivity.

EVOLUTION OF CELLULAR IOT

Most Cellular IoT devices in the field today use GPRS as a basic communication protocol. The GPRS (GSM) format has been available for more than 20 years and as a result, the cumulative total number of devices is significant at about XXXX devices. CDMA and W-CDMA (UMTS and HSPA) devices also exist out in the market, but with lower numbers due to smaller regional deployments and less time on the market.

LTE has only been deployed for a few years so far, so the number of LTE devices is still ramping up. Multiple LTE variations are possible, ranging from high throughput (Cat 13 in uplink) to lower throughput (Cat-M1).

Many people would say that NB-IoT is also another category of LTE connectivity because it's designated as Cat-NB1 in 3GPP committees. We treat NB-IoT as a separate format because the basic RF waveform is different than LTE and does not rely on the same resource block allocations as the other levels of LTE.

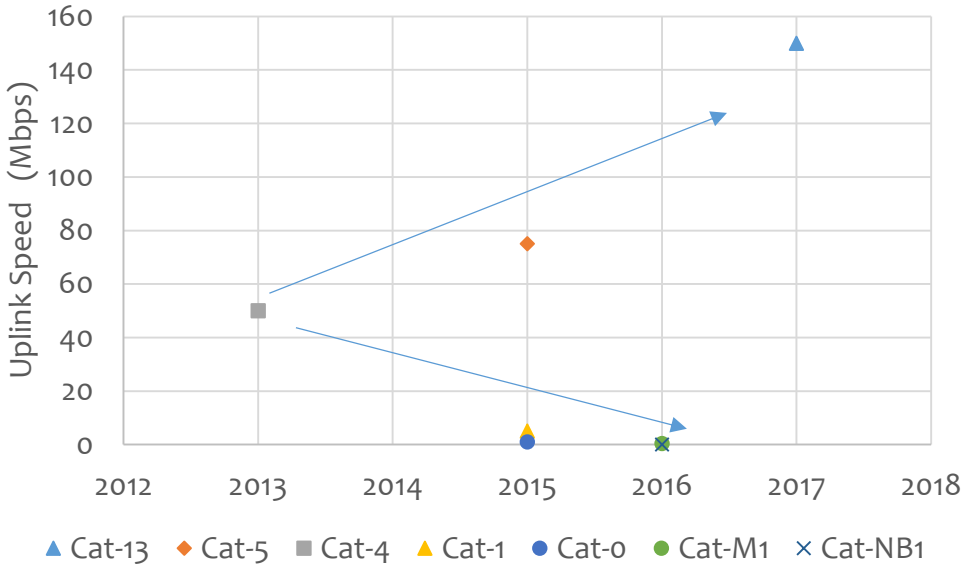

Figure 4 Evolution of LTE M2M formats over time

Source: Mobile Experts. Timing based on chipset availability

Notably, the LTE formats have evolved in two directions over the past several years. Since the first introduction of LTE modems with Cat-4 operation, the uplink has evolved in two directions at the same time: upward to Cat-13 operation in 2017, and downward to Cat-1, Cat-0, Cat-M1 (LTE-M), and Cat-NB1 (NB-IoT).

We charted these formats according to uplink speed, not downlink speed, because (unlike broadband apps where downlink is king) the uplink is the best metric for progress in IoT applications. In fact, the downlink has continued to progress upward with recent modem releases supporting up to 1.2 Gbps in LTE-Advanced, without upgrades to the uplink above 150 Mbps.

The question today remains: What is the next step in IoT? Is it higher uplink throughput? When we see our first 5G NR modems that are cost-optimized for IoT, will they focus on the high-throughput applications with 150 Mbps or more, (along with lower latency), or will they target the low-throughput market similar to NB-IoT, (again, with lower latency)? The market indications are not clear today.

WHICH TECHNOLOGIES WILL WIN?

Mobile Experts is tracking at least 75 different ways to connect IoT devices. To sort out the likely match between so many connectivity options and the market opportunities, o make sense of the market, Mobile Experts uses seven technical factors to differentiate market segments:

- Connection Range
- Data Speed
- Latency
- Reliability
- Functionality (One way, two way, OTA updates)
- Battery Life; and
- Cost (device cost, network cost, and service operating cost)

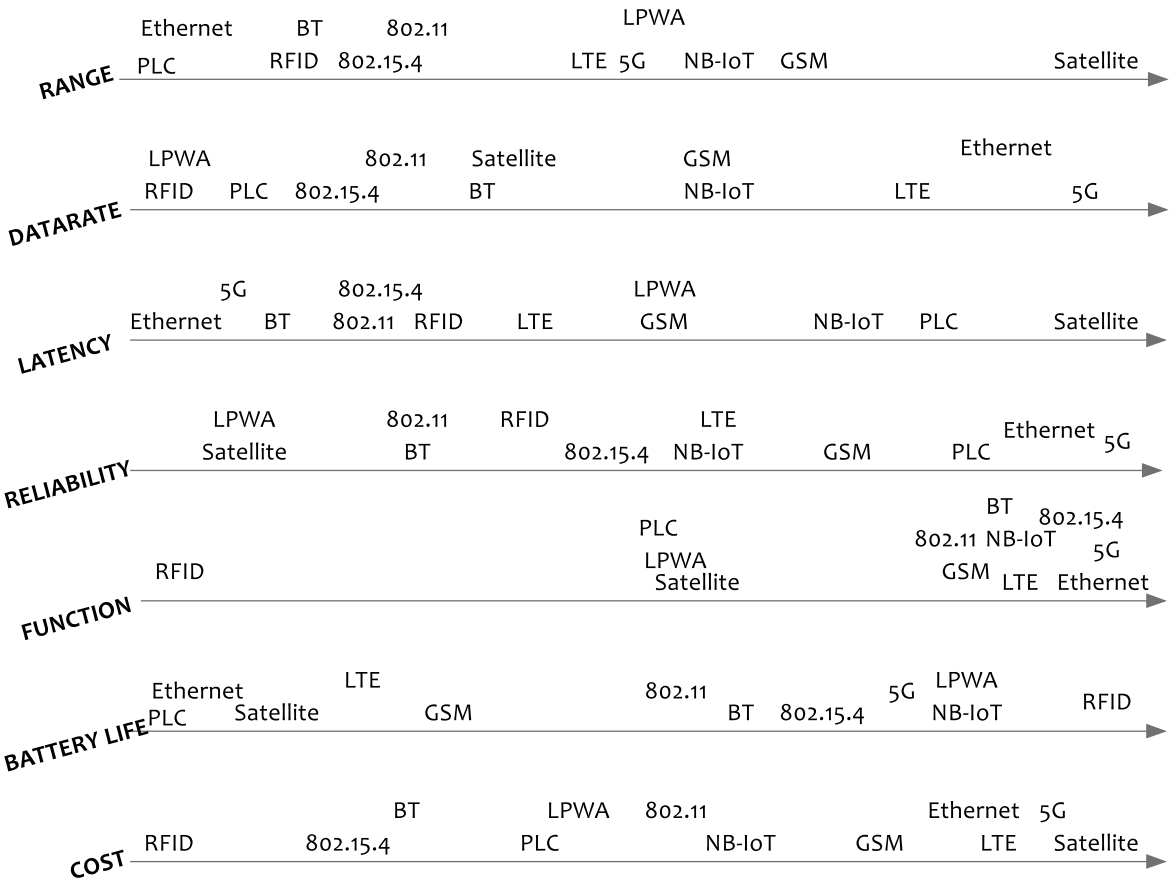

Figure 5 Seven Technical Factors that Differentiate IoT Applications

Source: Mobile Experts

Based on technical factors only, the broad variety of Cellular IoT standards can cover a broad range of market applications. GSM technology operates over long range. LTE handles high throughput. NB-IoT is coming to the market to offer long battery life. This report identifies the technical areas that match with each C-IoT format.

However, in addition to technical factors, business model factors must also be considered. NB-IoT may be a fairly low cost technology, but some customers are not willing to rely on a mobile operator. Some customers and applications simply are not suitable for any service provider to be involved, due to the localized and personal nature of the device.

3 APPLICATIONS FOR C-IOT

Mobile connectivity has a huge range of possibilities, from simple stationary objects with very small data packets to moving platforms with heavy throughput. Last year, we looked at applications according to technology, but this year we have chosen to break down the market according to broad vertical market areas. In each area, illustrating the evolution of cellular standards (from GSM through 5G NR) can be instructive to the priorities of the end customers.

AGRICULTURE APPLICATIONS:

Farming has used automation for many years, with tractors and other farm equipment adopting GPS-based location awareness and automated driving to save labor costs and increase productivity. Big farming machines have plenty of electrical power, so connectivity using GSM or 3G technology was acceptable. Newer applications are now coming to market, taking the low power consumption of LTE-M and NB-IoT into account and allowing for small battery-based devices.

In agriculture, applications include:

- Soil moisture monitoring
- Vehicle and farm equipment automation
- Drone-based inspection of crops
- Drone-based "scarecrow" systems
- Livestock and equipment location tracking

The early applications had limited production volume due to the very expensive nature of highly automated trucks and harvesters. However, as we shift to small battery-fed devices the number of agricultural IoT devices will increase dramatically.

The major question in this application area is whether cellular IoT is the preferred mode of communication. Does the farm have adequate cellular coverage? If so, then most farmers will prefer to use an existing network—every operation from small landholders to huge industrial operations are likely to prefer an existing cellular network.

In areas without good cellular coverage, LoRa networks may emerge. We see investment in this direction by companies like Senet in the United States… the idea is that the cost of coverage per square kilometer is lower than an LTE-based network, and without licensed spectrum the deployment can be achieved much more quickly.

ASSET TRACKING APPLICATIONS:

Mobile Experts has examined six major areas of asset tracking, which occupy very different vertical markets but share many consistent themes in terms of tracking the location of devices. In particular, we focus on:

- Livestock (mainly cattle tracking): About 1 million cows are tracked today with collars or tags that use unlicensed LPWA or GSM/3G radios. We expect two technologies to dominate this segment in the long term: NB-IoT (where available) and LoRa (where no LTE-based options are possible)
- Healthcare applications are a very hot growth segment, given the need to monitor and track the shipment of drugs, some of which must be monitored for temperature. Inside hospitals, Wi-Fi has been used for years to track expensive machines on wheels. Over time we expect almost all of these apps to move toward NB-IoT or LTE-M.
- Industrial operations need to track the location of various items. The items tracked can include products during manufacturing, trucks in a wide-ranging mining, logging, or energy operation, and other high-dollar items. In many cases these industrial operations are outdoors and require long-range technology for connectivity over a few miles… so NB-IoT technology may be ideal.
- Transportation: Asset tracking in the logistics area can range from tracking cargo ships to steel containers, to pallets or even individual boxes. Satellite-based devices are generally used for the ships, but as we move down to containers, pallets, and boxes the cost pressure is increasingly higher and low-cost devices are in demand. In these cases, global interoperability and connectivity are key features, so GSM still has a significant role today. Emerging standards like NB-IoT can reduce cost and make pallet or box tracking more practical.
- Retail operations generally use Bluetooth or Wi-Fi, with less use of cellular technology.
- Consumer devices have some extreme cost limitations, so unlicensed LPWA technology will be preferred in some cases (Sigfox has established some very low price points, so even in the likely case that Sigfox does not survive we expect the low pricing to remain). In other cases such as bicycle rentals, NB-IoT technology is expected to sweep across the market.

AUTOMOTIVE APPLICATIONS:

The automotive market is the ideal case for 3GPP-based technology. Auto manufacturers are not interested in deploying their own networks, but the dollar value on telematics information or insurance information can be high. Most cars sold over the next 10 years will include some level of LTE technology.

Key applications in the automotive sector include:

- Telematics: Reporting data on the car's operation can be useful to the OEM for maintenance and even prediction of failures to enhance reliability. Data throughput requirements can be fairly low in this case, although over-the-air firmware updates can involve huge amounts of data in some cases, requiring high-level LTE operation.
- Infotainment: Web entertainment in the car has become a luxury feature on the market that will not go away anytime soon. This feature can often cause an upgrade in requirements for the telematics modem to include high download speed.

Currently automotive manufacturers are moving to Carrier Aggregation to support high data speeds at Cat-6 through Cat-18 levels in the downlink.

- Aftermarket fleet management devices are another strong element. A module that plugs into the OBD-II port in a car can report data back to a fleet manager as in a rental car, or can report data to an insurance company in a business model known as Usage-Based Insurance. Power is not a major concern but reliable connectivity in wide coverage is key. LTE-M is emerging as a popular technology for this product area.

BUILDING AUTOMATION APPLICATIONS:

Smart home automation was an early focus area for the IoT market, using Wi-Fi, Bluetooth, and 802.15.4 technologies. But as larger buildings are addressed, the limitations of these short-range formats becomes more obvious. Larger buildings have a more compelling need for security, as well as automation of systems such as air conditioning, water, and heat.

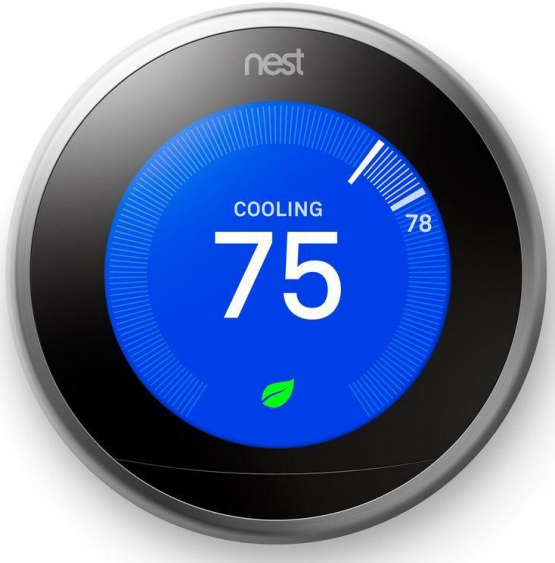

Figure 6 A Nest thermostat has limitations in range and ease of use with Wi-Fi

Source: Alphabet/Nest

As the commercial market matures, we expect the existing building-automation suppliers (such as Johnson Controls, Honeywell, and Siemens) to adopt LoRa technology in some cases. The license-free operation of LoRa is appealing, along with its long battery life and long range. It's possible that unlicensed variations of LTE may enter this market area in the

future as well, but the question is whether LoRa can penetrate enough products in the market over the next five years, before LTE-U has matured enough to be a major contender.

HEALTH-CARE APPLICATIONS:

Leaving asset tracking applications aside, some interesting health-care applications are starting to emerge for Cellular IoT. Smart pill bottles are now available that track whether/when medication is taken by the patient. Wearable patches have reached the market using LPWAN technology to report patient vital signs after release from medical care. Smart scales have been developed for doctors and/or health coaches to monitor the progress of an end user.

Figure 7 Smart pill bottle using a 3G radio

Source: Adhere Tech

In all of these cases, Wi-Fi and other short-range technologies have been tested, but in almost every case there's a group of health-care pros that prefer mobile technology. Mobile formats such as LTE-M or NB-IoT offer good coverage in most patient homes, but does not require the patient to tether the device to a smartphone or a local Wi-Fi access point. Doctors simply feel that relying on the patient to take these technology steps would severely limit the usefulness of the system.

Figure 8 A "smart patch" for clinical monitoring

Source: Karten Design

INDUSTRIAL APPLICATIONS:

Several industrial areas include opportunities for cellular IoT devices. Key categories include:

- Oil & Gas exploration, drilling, and transport requires a lot of simple information in remote locations. Technicians waste a lot of time driving out to a wellhead to check on whether a tank is full, or whether the pump is running smoothly. Where LTE coverage is available, these devices will generally use it. In other places, U-LPWA coverage has been deployed to cover the oil fields. This is a particular strength for Ingenu and their RPMA technology.
- The electrical grid requires sensors to monitor performance, as well as switches and other actuators to make changes for real-time grid management. Some large utilities use proprietary RF networks for the grid and for smart meters. Smaller utilities are more willing to rely on a local LTE network.
- Manufacturing operations need to run all of the time—work stoppage can cost millions of dollars for some manufacturing or process control operations. In a jet turbine assembly line or a giant brewery operation, sensors to monitor temperature, machine vibration, and many other variables can be an important part of predictive maintenance. In most cases this is handled with wires today, (Fieldbus or Ethernet), but flexible factories need high-throughput links without wires, and LTE can offer a more reliable alternative than Wi-Fi or other formats.
- Industrial-level transportation systems should be a strong growth area for LTE technology. GSM has been used for many years in train control and related communications… and in fact a separate band has been set aside for GSM-R in the 873-880 MHz band (uplink) and 918-925 MHz band (downlink). Advances in 3GPP will move the rail market into LTE-based communications to allow for higher throughput and lower latency. Airports are another key application, with a desire to download data from aircraft, as well as other applications (such as baggage tracking and security systems) that we cover in the Asset Tracking and Building Automation segments.

SMART CITY APPLICATIONS:

Mobile Experts defines the Smart City area as a series of applications that the municipal government will pay for. In this way, the business model can be very different than the Asset Tracking market, the Industrial market, and other segments where very similar technology solutions will be seen. Smart cities include:

- Smart street lighting is normally the place that a city will begin. The streetlights are often upgraded from the old sodium-based lights to LED lighting along with the network deployment.
- Traffic management solutions can be added to improve on positive control of traffic signals, using sensors and cameras to paint a picture of the overall traffic situation in a city.
- Smart waste management: This simple use case optimizes the routes and timing of garbage trucks, to ensure that "full" waste bins are emptied while "empty" bins are bypassed.
- Smart Parking systems: With sensors in the parking lot, drivers can be directed to an open space.
- Other applications include specialty systems such as pollen monitoring, gunshot location/detection, facial recognition, license plate identification, as well as basic utilities such as water/gas/electrical service.

Figure 9 A "Smart Street Light" upgraded to monitor the environment

Source: Telensa

SMART METER APPLICATIONS:

While smart meters can be viewed as an extension of the smart city, Mobile Experts tracks it as a separate category due to the far higher level of maturity of the market and the distinction between utility companies and municipal governments. (Some cities are also utilities, but on the whole the utilities and city government make decisions differently).

The smart meter application is pretty simple: Radios or power-line based IoT devices communicate usage information for electricity, water, gas, or heat to the utility. The original applications were developed as Automated Meter Reading (AMR) systems to allow for quicker meter-reading on a once-per-month drive-by basis. More recent systems have evolved as Automated Metering Infrastructure (AMI) which often reports usage data every 15 minutes. In addition to simply reporting usage, AMI can be used to enable and disable service, detect leaks or other problems, or even enable connectivity for the customer to see a real-time view of energy pricing, usage, or other information.

Figure 10 A Smart Meter example

Source: EVB Energie AG

LTE-M and NB-IoT technologies are expected to open up new areas in the Smart Meter market, as smaller utilities that have not chosen to deploy their own networks can now access reasonable solutions on an existing cellular network.

4 CELLULAR IOT TECHNOLOGIES

The roadmap of M2M or C-IoT technology is a long one, starting with early AMPS systems and CDPD… and leading to future ideas for 5G NR-based machine connectivity. It's important to distinguish between two eras in machine communications:

- M2M, (roughly 1990 to 2017) where machine communications simply took advantage of a network that was optimized for other purposes; and
- IoT (starting in 2017) where new cellular IoT formats are optimized for machines. LTE-M and NB-IoT belong to this category, where the air interface is scaled back to allow for longer battery lifetime.

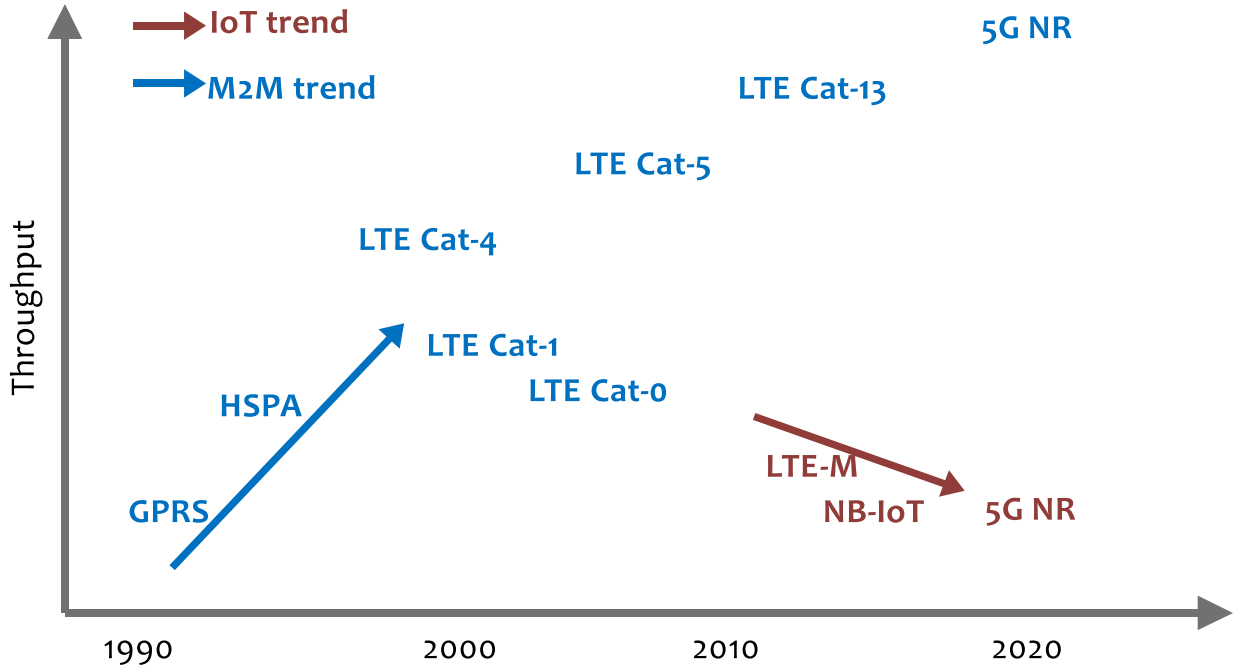

Figure 11 Illustrating the Difference between M2M and IoT

Source: Mobile Experts

Throughout the history of the M2M era, devices used cellular connectivity because it was the most convenient platform, not because it was the best technology for the purpose. Decisions about network connectivity or which device to use are made based on whatever is available. This trend continues with LTE Cat-5, Cat-13, and 5G NR devices that re-use smartphone devices for IoT applications.

However, as we go into the future, we expect the market dynamic to change. Starting in 2017, we saw dedicated Cellular IoT deployments with NB-IoT base stations shipped into China in large numbers as well as deployments in other key markets. Today, the air interface technology is tailored for small bursts of data over a longer range.

Standard	Channel Bandwidth	Downlink Throughput	Uplink Throughput	Latency	Comments
GPRS	200 kHz (divided into time slots)	9.6 kbps (one time slot)	9.6 kbps (one time slot)	500+ms	Large legacy installed base
HSPA	5 MHz	Up to 42 Mbps	Up to 22 Mbps	100+ ms	Multiple variations not covered in detail here
LTE Cat-4	20 MHz	150 Mbps	50 Mbps	10-50 ms	Basic symmetrical operation
LTE Cat-5/6	2x20 MHz	Cat-6, 300 Mbps	Cat-5, 50 Mbps	10-50 ms	
LTE Cat-13/12	3x20 MHz	Cat-12, 600 Mbps	Cat-13, 150 Mbps	10-50 ms	
LTE Cat-13/16	4x20 MHz	Cat-16, 800 Mbps	Cat-13, 150 Mbps	10-50 ms	
LTE Cat-13/18	5x20 MHz	Cat-18, 1.2 Gbps	Cat-13, 150 Mbps	10-50 ms	
LTE Cat-1	20 MHz	10 Mbps	5 Mbps	10-50 ms	
LTE Cat-0	20 MHz	1 Mbps	1 Mbps	10-50 ms	Nobody uses this standard
LTE Cat-M1 (LTE-M)	1.08 MHz	300 kbps	375 kbps	10-50 ms	Release 13
LTE Cat-M2	5MHz	2.3 Mbps	1.5 Mbps	10-50 ms	Release 14
LTE Cat-NB1 (NB-IoT)	180 kHz	27 kbps	65 kbps	10-50 ms	Release 13
LTE Cat-NB2	180 kHz	87 kbps	60 kbps	10-50 ms	Release 14 variation
5G NR	TBD	TBD	TBD	1 msec expected	Standards not completed yet. Expect multiple variations.

Figure 12 Distinctions between 14 different Cellular IoT air interface standards

Source: Mobile Experts

COST PER GB OF DATA:

The shift from a "tag-along" technology to a new network creates an unusual dynamic in terms of the business model. Mobile operators have always been able to profit from data over the M2M network, because the handset business covered the costs. Realistically, CDPD, GPRS, or LTE M2M networks would never have been built as stand-alone networks because the revenue would not justify spending so much money on the radios.

Note that in our calculations, we assume similar utilization between smartphone networks and IoT networks. As a result, for the short term the IoT costs shown in the below chart are probably understated, because the low numbers of IoT devices will drive low utilization of a stand-alone IoT network.

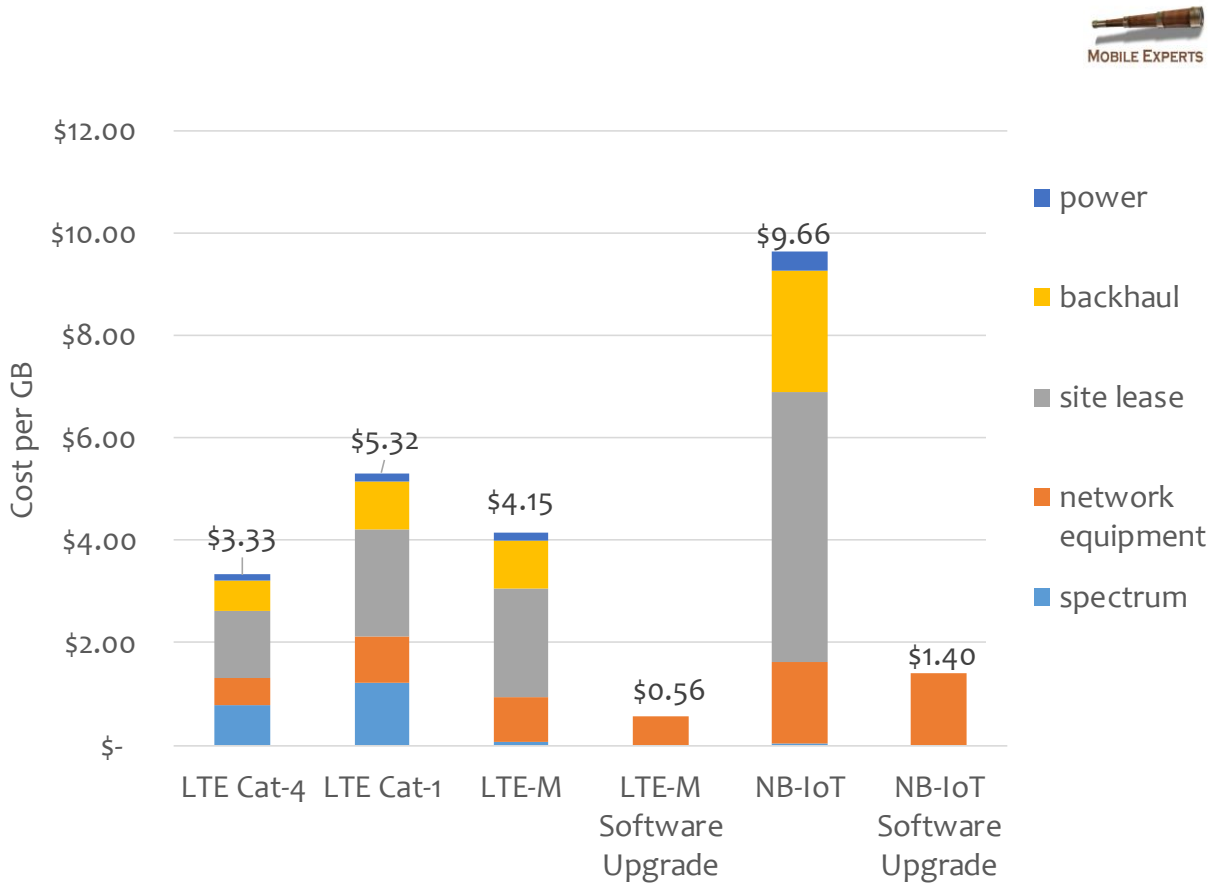

Figure 13 Total Cost of Ownership per GB of Various M2M and C-IoT Standards

Source: Mobile Experts

The key message in the TCO calculation is that an overlay IoT network (as a software upgrade to an existing LTE network) can be an inexpensive way to add capacity. Mobile operators can charge between $5 and $50 per GB for IoT data, depending on the business

model involved. An LTE-M or NB-IoT network that shares capacity with the smartphone network is a clear winner, since the retail price per GB rises and the cost per GB drops.

We've now reached the point where market expectations are large enough to justify stand-alone C-IoT networks….and at the same time, existing networks enable inexpensive overlays of IoT networks using software upgrades.

ENERGY PER KB OF DATA:

The efficiency of the radio link is improving as we optimize technology for long-life batteries. A typical GPRS modem consumes 0.8 mA of current (3.5V) or about 2.8 mW of power in idle mode, and up to 960 mW in active transmit mode….to transfer 9.6 kbps of data. HSPA and LTE evolution took the power consumption in the wrong direction, increasing the current consumption for the device and thus shortening the battery lifetime.

LTE-M and NB-IoT allow for the IoT devices to go to sleep using the Release 13 Power Saving Mode (PSM), thus dramatically reducing the energy consumption from "idle" mode to "sleep" mode. In addition, the optimization of the air interface for small packets allows for the active current draw to be far lower.

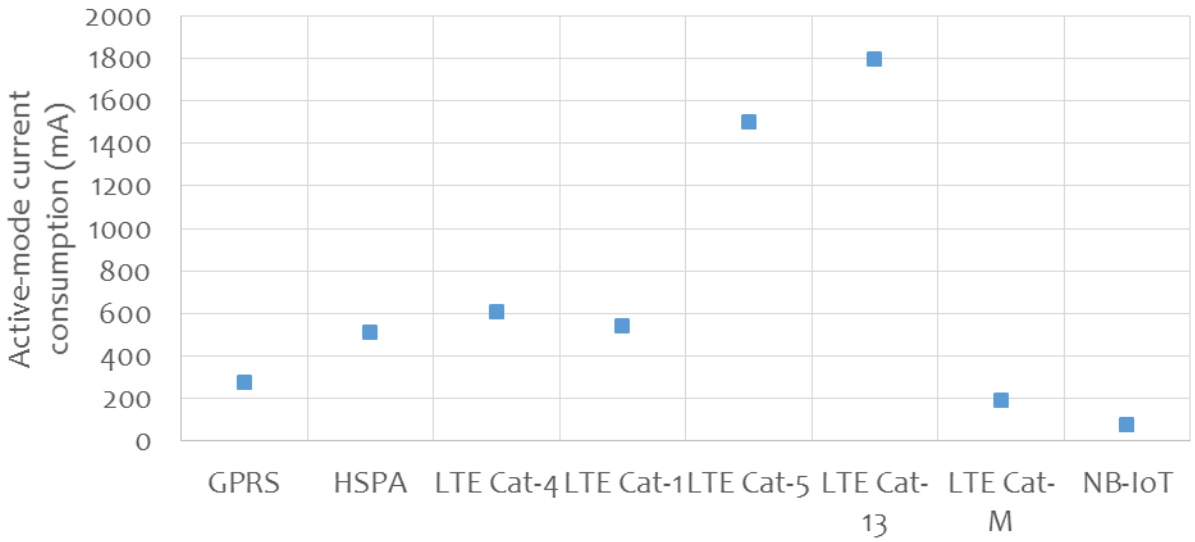

Figure 14 Current Consumption for various M2M and C-IoT formats

Source: Mobile Experts

The current consumption is lower for LTE-M and NB-IoT, but the data throughput is also lower than other cellular standards. So are the new formats really more energy efficient? The short answer is yes. Because PSM allows the device to drop from "idle" mode to a much more dormant state, for most of the time the current consumption drops from about 1 mA to a few microamps.

The true power savings for LTE-M or NB-IoT will depend on the application, and how often the device drops into a deep sleep state. For a typical application (with 10 kB sent every 15 minutes), the power savings of PSM is significant.

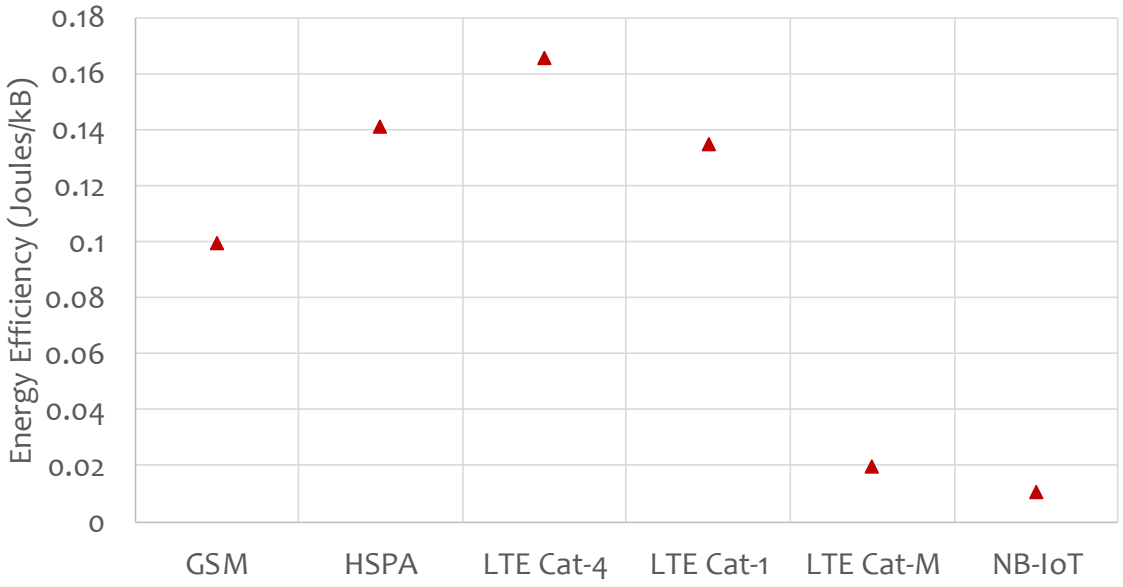

Figure 15 Energy Efficiency (Joules/kB) for various M2M and C-IoT formats, 15 minute intervals

Source: Mobile Experts

However, in a case where data is sent more continuously, PSM has less impact and Cat-M looks very similar to Cat-1. In the below chart, the IoT device spends 10 seconds in either "idle" or PSM mode, then sends its 10 kB packet.

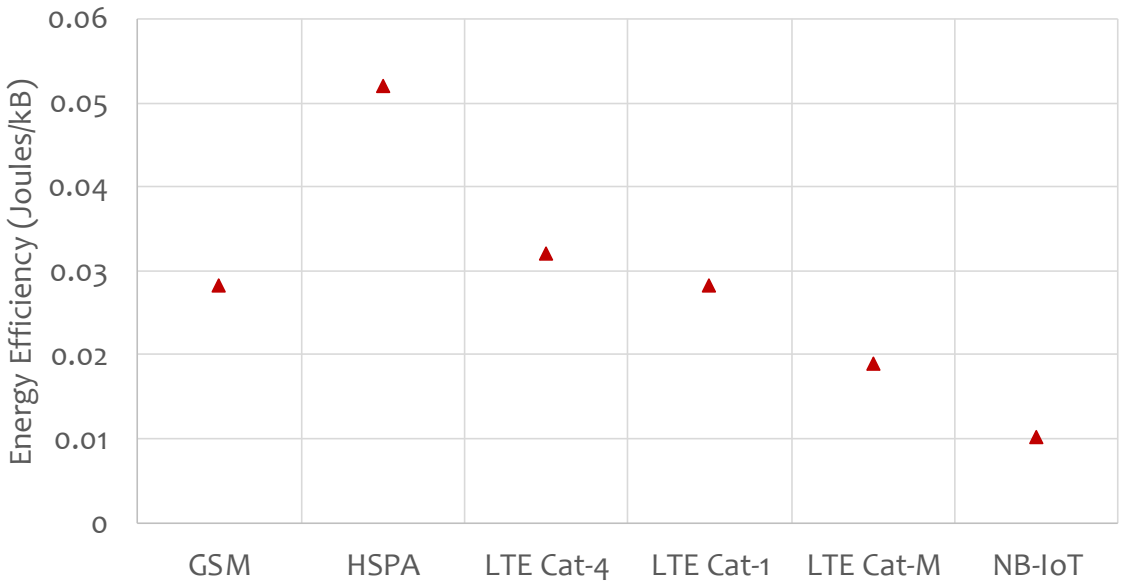

Figure 16 Energy Efficiency (Joules/kB) for various M2M and C-IoT formats, 10 second intervals

Source: Mobile Experts

COST PER SQUARE KILOMETER OF COVERAGE:

The cost of the network is a difficult concept to quantify, because each operator accounts for the IoT network differently. To make a valid comparison, we amortize the total cost of ownership of mobile networks, according to data usage.

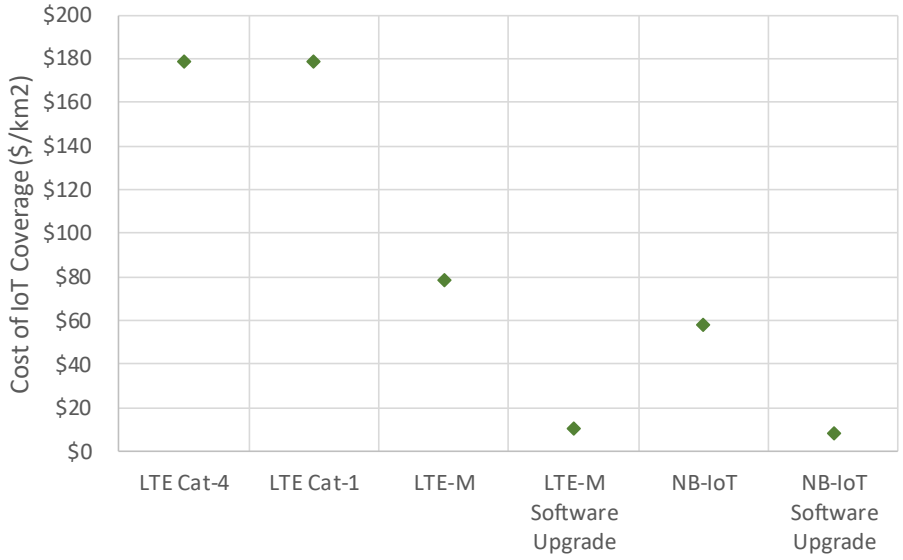

Figure 17 Cost per Square Kilometer ($/km2) for various M2M and C-IoT formats

Source: Mobile Experts. Total cost of ownership per square kilometer shown.

Looking at the apples-to-apples comparison of a new Cat-4 network vs. a new LTE-M network, for each square kilometer of coverage the Cat-4 network is roughly twice as expensive. Compared with a new NB-IoT network the cost difference is roughly triple.

The cost comparison is even more compelling when looking at true costs. Because LTE-M or NB-IoT are normally deployed as a software upgrade to an existing LTE site, the cost is much lower in reality than a new greenfield network. For a deployment of NB-IoT, the real-world TCO is likely to be only about $8 for every square kilometer.

WHAT ABOUT 5G IOT?:

The hype and expectations for 5G NR are very acute in the market, and many people have unreasonable expectations for 5G NR to quickly replace LTE-M or NB-IoT in high volume applications. Multiple challenges will prevent this:

1. Each vertical market will settle on its preferred IoT connectivity standards over time. Some markets such as smart meters, street lighting, and asset tracking are already settling down with big leading enterprises making technology choices. Once this choice is made by the leading customers, we don't expect a change in formats to be easy. 5G is late to the party.
2. The modems and related devices will not be cheap for 5G. Assuming that a 5G IoT modem chip will be cheaper than a NB-IoT chip is a very dangerous assumption at this point in time.
3. 5G coverage will be quite limited, especially in regions such as Europe where 5G investments will not begin for at least four more years. Even in Korea, Japan, and most US networks, we expect 5G deployment to happen in the urban center but not in rural areas. The mobile broadband application that drives the ROI decision for the operator is viable in the city, but not in rural areas.
4. The 5G deployments on the horizon will use high frequencies, ranging from 3.5 GHz to 39 GHz. These bands are not well suited to IoT applications where a high degree of reliability is required over long distances. The 5G format could be useful for high-reliability communications in a factory environment, but for long-range outdoor use these bands are not the right choice. Waiting for 5G deployment in the 600-900 MHz bands could require another 10 years. (Note: There's one exception with T-Mobile USA, who will be deploying nationwide 5G in the 600 MHz band in the USA)

WHICH CELLULAR IOT STANDARDS WILL BE USED?:

Not all of the 14+ variations of Cellular IoT are recommended for new devices in the future. Here are some simplified conclusions:

- GPRS has a huge installed base but the longevity of the network is likely to be short;

- HSPA consumes a lot of power and networks are likely to be shut down soon;
- LTE Cat 4 through Cat 18 variations are useful for high-throughput apps but only where power efficiency is not critical.
- LTE Cat 1 is likely to die because it's fairly new and Cat-M and NB-IoT will take over the low bandwidth applications;
- LTE Cat-0 has already died from lack of benefit compared with Cat-1;
- LTE Cat-M is actually cheaper than NB-IoT for each kB of data and has higher throughput for voice apps and other uses, so Cat-M will be useful.
- NB-IoT has low power consumption and low cost for coverage. We expect NB-IoT devices to be 30% cheaper than Cat-M devices due to Chinese chipset development. This will be the biggest winner in terms of volume deployment;
- 5G NR has the advantage of low latency but other factors are likely to be a problem, including high cost and higher power consumption. We expect 5G NR IoT to be a niche solution for low latency, for automation use cases.

5 MARKET CHALLENGES

The number of applications and the pent-up demand for automation indicates strong growth for the future. There's a word now for connecting devices: "IoT-ification". But despite the broad consensus for strong market growth, some major roadblocks stand in the way of cellular-based IoT technologies.

OPERATOR SALES CHANNELS:

Most mobile IoT applications target an enterprise customer, whether it's an insurance company or a hospital or a car rental company. Mobile Experts anticipates that roughly half of IoT devices will be sold to enterprises (with the other half related to smart-home and other consumer use cases)….but more than 75% of IoT device revenue will derive from enterprises.

The primary driver for the Cellular IoT market, therefore, will be in cost savings for the enterprise. Any application that saves money for a business through automation will be developed over the next 10-20 years. The obvious applications with the highest stakes are already well developed: Utility meters, fleet management systems, automotive telematics, and remote financial transactions.

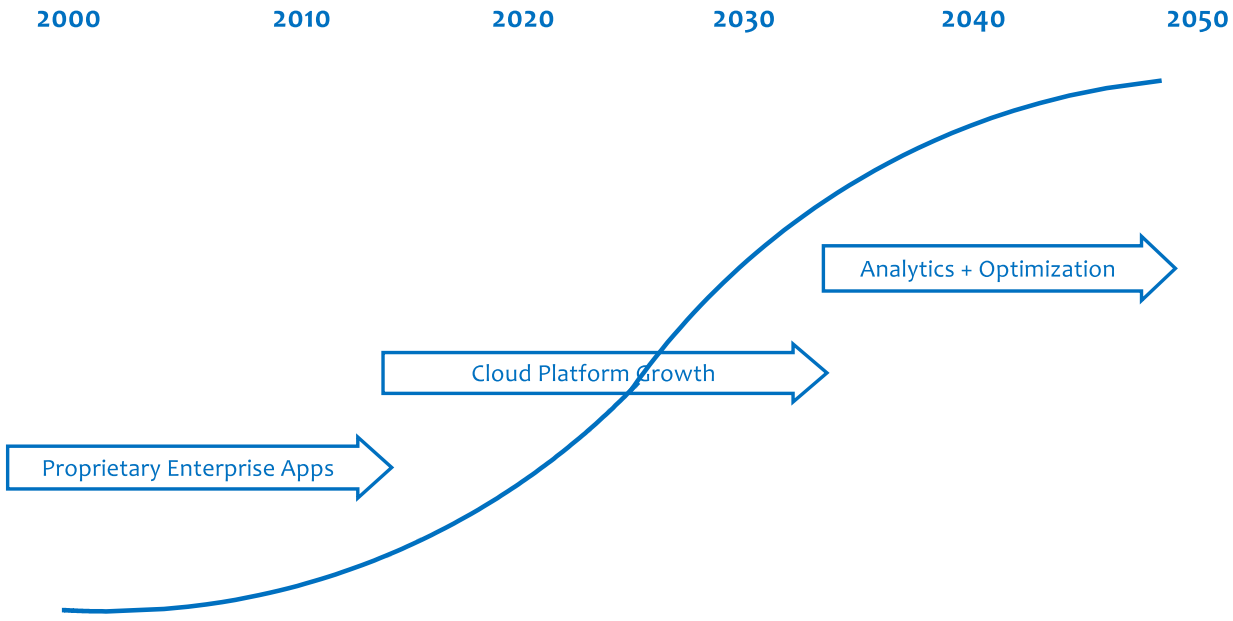

Figure 18 Phases of IoT market development

Source: Mobile Experts

The early development of the enterprise business model has been internally driven by specific large enterprises. As an example, large electric utilities worked with mobile operators to develop GSM-based modems for smart metering. It's important to understand that this early market development was not driven by a global trend to IoT, or by the new availability of any specific technology. It was simply driven by the strong leverage of huge cost savings, addressed by a relatively small investment in devices.

Here's the problem: Mobile operators are not good at selling services to enterprises. The typical mobile operator knows how to sell a consumer phone plan to individuals, but the process of selling to enterprise customers requires a very different organization.

Some enterprises such as manufacturing companies, large utilities, and building-automation companies will require guarantees in terms of network reliability. Operators don't like to sign up to any kind of guarantees because network performance is sure to change as consumer usage continues to increase.

Another challenge arises in the area of longevity. Many enterprises want to make investments with a 20-40 year lifespan for technology. The mobile operators cannot predict what technology they will be using in the cellular network 20 years in the future. Any agreement to maintain operation of GSM for the next 10 years is doubtful today, and any agreement to keep LTE going for 40 years would also be doubtful.

CHALLENGES IN KEY VERTICAL MARKETS:

The enterprise market will drive serious growth in C-IoT, but a few roadblocks remain in the way.

- Regulatory decisions have slowed down the automotive V2V market. In the United States, ten years of development was expected to lead to a government mandate for 802.11p vehicle-to-vehicle communications in every car. However, President Trump's administration chose not to require this feature in new cars….throwing the adoption of this technology into doubt.
- Unlicensed LPWA vendors have been very active in a few key vertical markets. Specifically, Ingenu has been quite successful in serving the Oil & Gas development market, offering IoT services where cellular coverage is weak in oil fields throughout the USA. Similarly, Telensa has developed a strong presence in the streetlight market, managing and packaging data in a way that is compatible with streetlight management systems as well as "smart city" applications that can live on top of the streetlights. Cellular IoT is already starting to be locked out of some niches like these because the raw C-IoT connectivity is less important than these more complete services.
- Cost is higher for C-IoT technology than for alternatives. LTE-M devices are still more expensive than Bluetooth or U-LPWA devices, in terms of semiconductor BOM cost

as well as the fixed costs of the mobile operators. This will remain true for many years, due to the higher complexity and higher transmitter power of licensed C-IoT.

6 OUTLOOK FOR CELLULAR IOT

The Cellular IoT market has grown nicely for several years, without having radio standards that are optimized for long battery life. Now that new standards allow for cheap, long-battery devices to be used, we expect new applications to drive higher growth rates. We are starting to see the investment in this direction with many different mobile operators, with the strongest jump in demand in China.

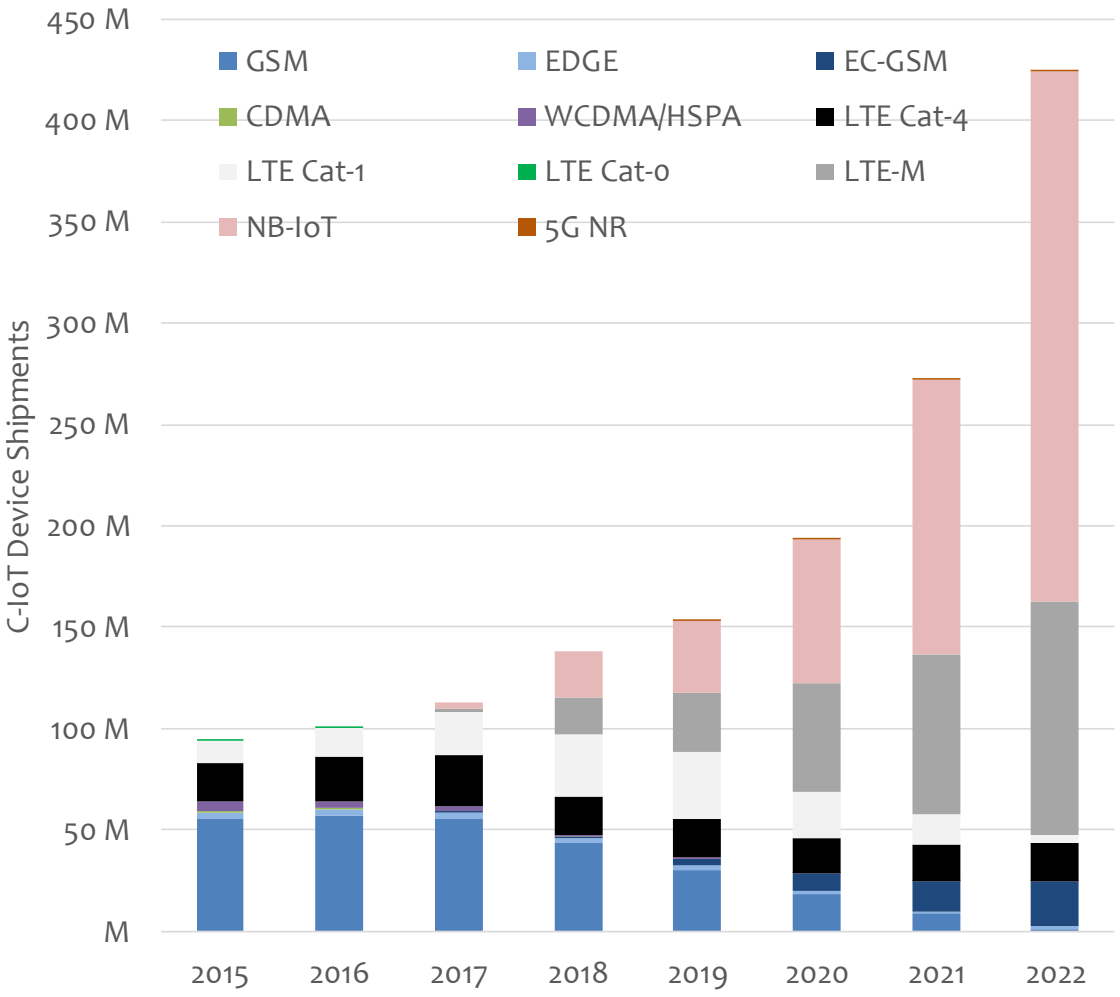

Chart 2: Cellular IoT Device Shipments, by technology, 2015-2022

Source: Mobile Experts

MOBILE VS. LPWA VS SHORT-RANGE WIRELESS:

The IoT hype often implies that 20 billion cellular devices will be deployed over the next few years. This is not the case. Many IoT applications (such as smart-home lighting, wearables tethered to a smartphone, or ad hoc enterprise devices) have no role for a mobile operator in the business model. This simple distinction cuts down the number of IoT devices in the mobile "sphere of influence" by half.

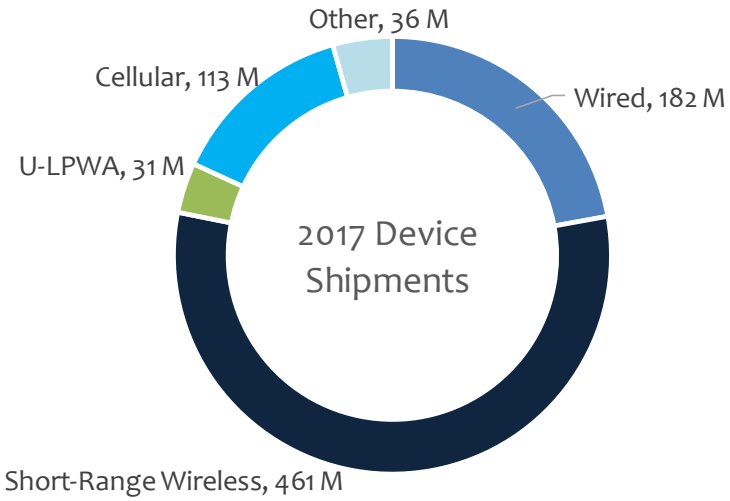

Chart 3: Comparison of Short-Range Wireless, LPWA, and Cellular IoT Shipments, 2017

Source: Mobile Experts

Over the next five years, Cellular IoT will get stronger as a share of the market. The outdoor and enterprise business models are expected to grow faster than the "smart home" and similar short-range IoT applications. This won't be a dramatic change but we will see increasing focus on higher power transmissions and 3GPP-based wireless formats.

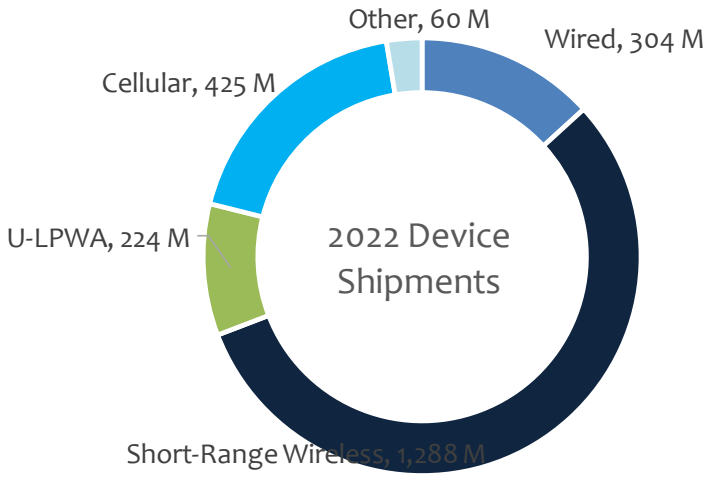

Chart 4: Comparison of Short-Range Wireless, LPWA, and Cellular IoT Shipments, 2022

Source: Mobile Experts

LTE-M AND NB-IOT VS. GSM, CDMA, EC-GSM, HSPA:

Looking at the cellular market a bit closer, we see a bigger shift taking place from the legacy "M2M" formats to newer "IoT" formats with much better battery life performance. In 2017, we don't see a lot of LTE-M or NB-IoT as they're in their infancy. But by 2022, we expect to see high level LTE in auto applications, but LTE-M and NB-IoT taking over most other applications.

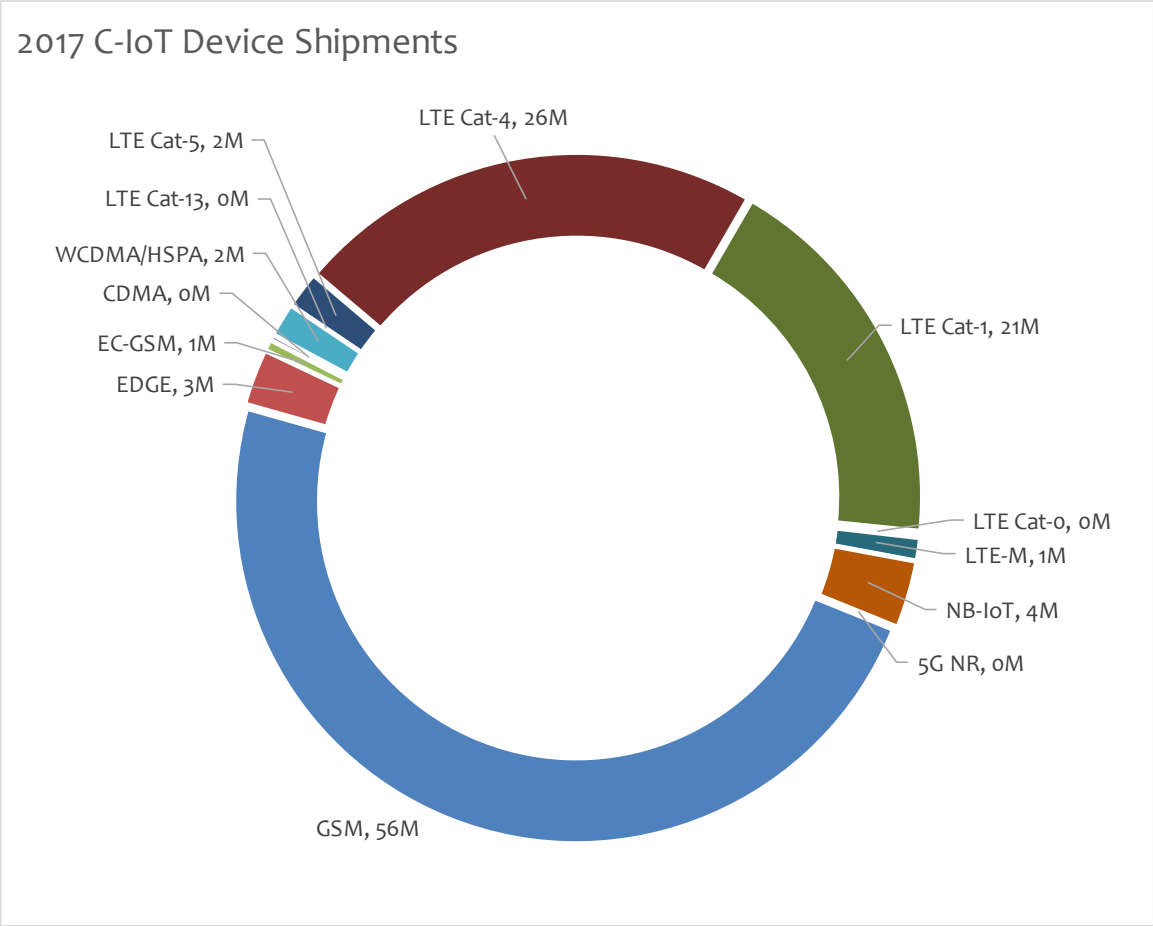

Chart 5: Technology Breakdown of Cellular IoT Shipments, 2017

Source: Mobile Experts

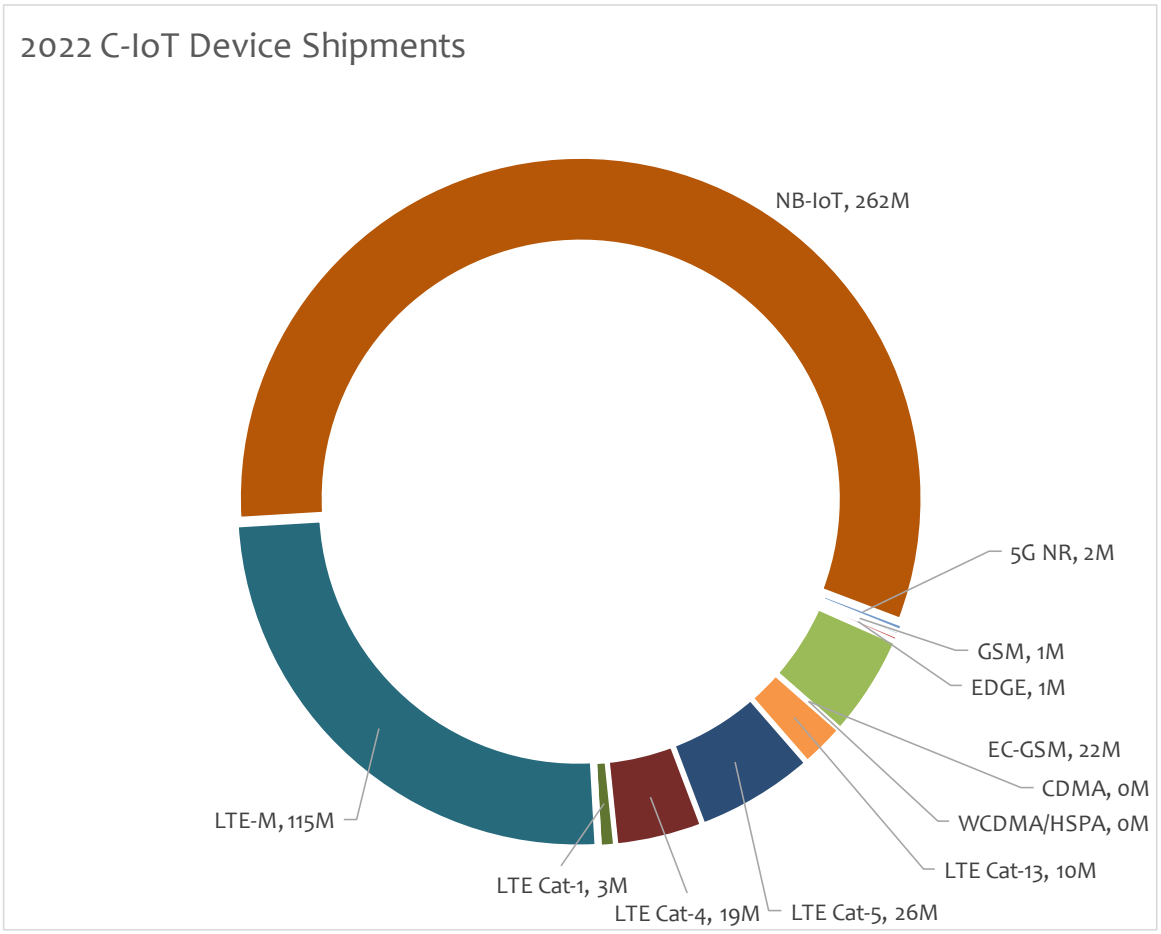

Chart 6: Technology Breakdown of Cellular IoT Shipments, 2022

Source: Mobile Experts

Several applications will account for major growth in C-IoT. This overall market growth is a pretty safe bet, because the risk is spread across markets ranging from automotive to healthcare, industrial, and Building Automation.

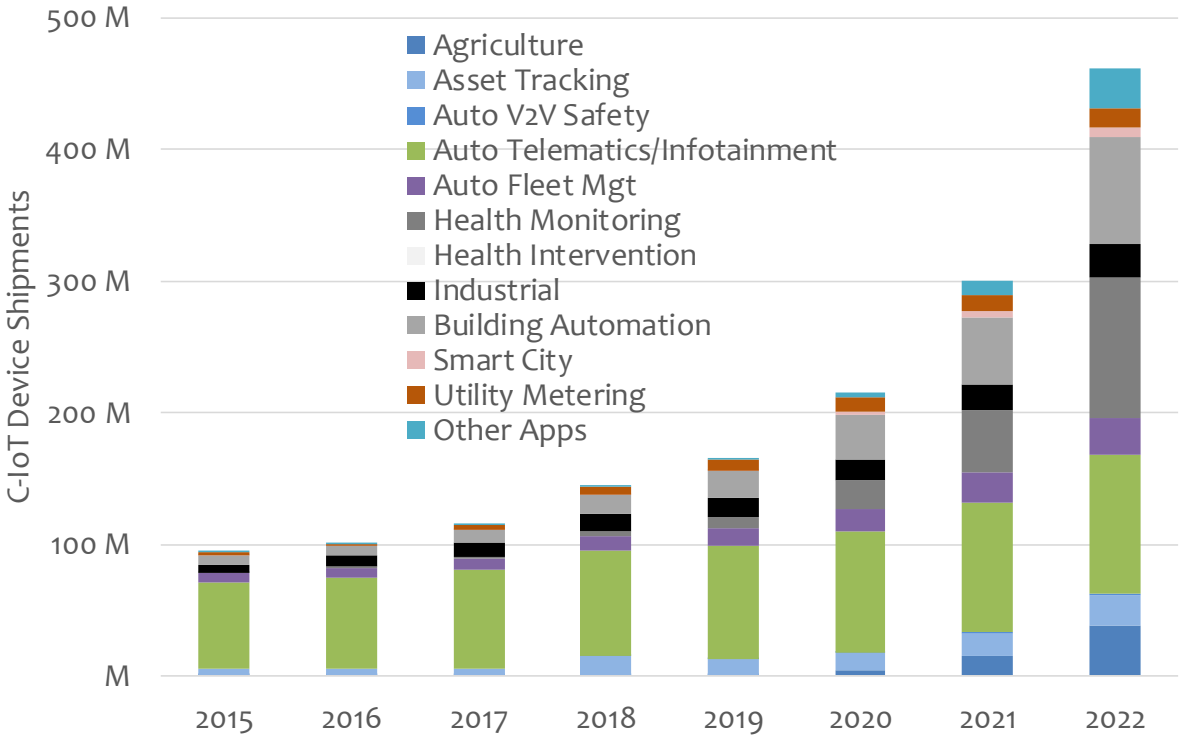

Chart 7: Cellular IoT Device Shipments, by application, 2015-2022

Source: Mobile Experts

The installed base of C-IoT devices has reached a level of about 500 million units. Most units remain in use for at least 10 years, so this number keeps growing steadily. Roughly 1.5 billion C-IoT devices will be in service by the end of 2022, about 17% of the total IoT installed base.

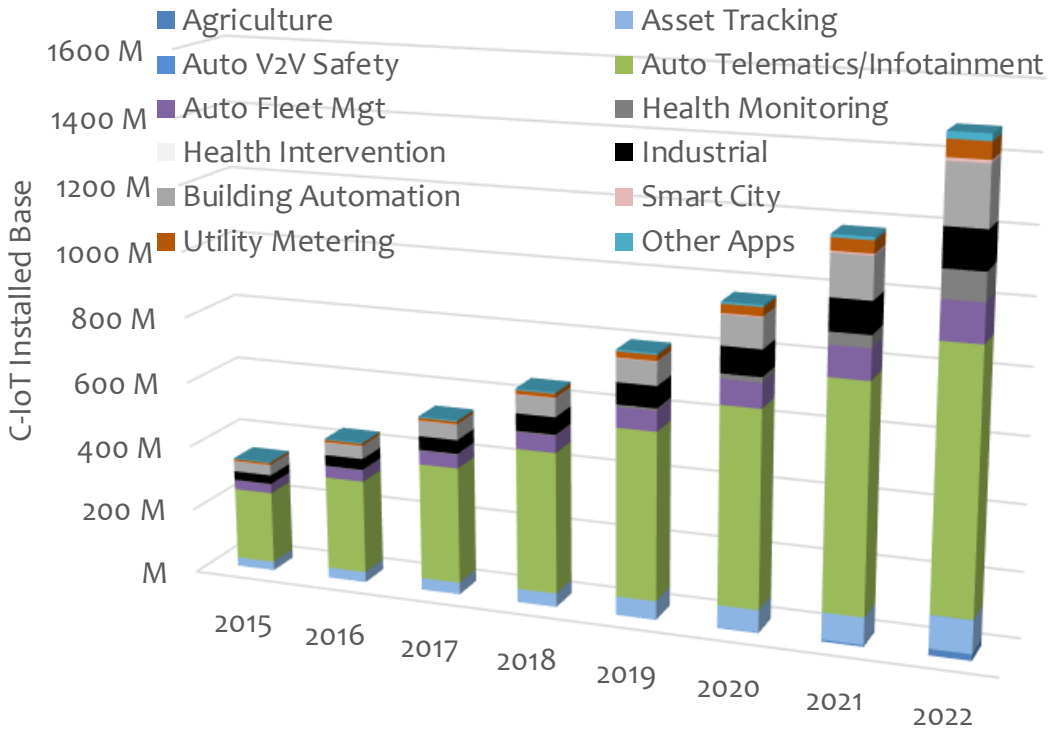

Chart 8: Cellular IoT Installed Base, by application, 2015-2022

Source: Mobile Experts

SERVICE REVENUE FORECAST

Many C-IoT devices will have low revenue per device—for example the Average Revenue Per Device (ARPD) will be lower than $1/month for agricultural devices or simple "button" devices that rarely report data-- due to direct competition with unlicensed LPWA. However, other applications can demand premium pricing. Drones and industrial users will pay $20 or more per device per month in many cases, bringing up the average.

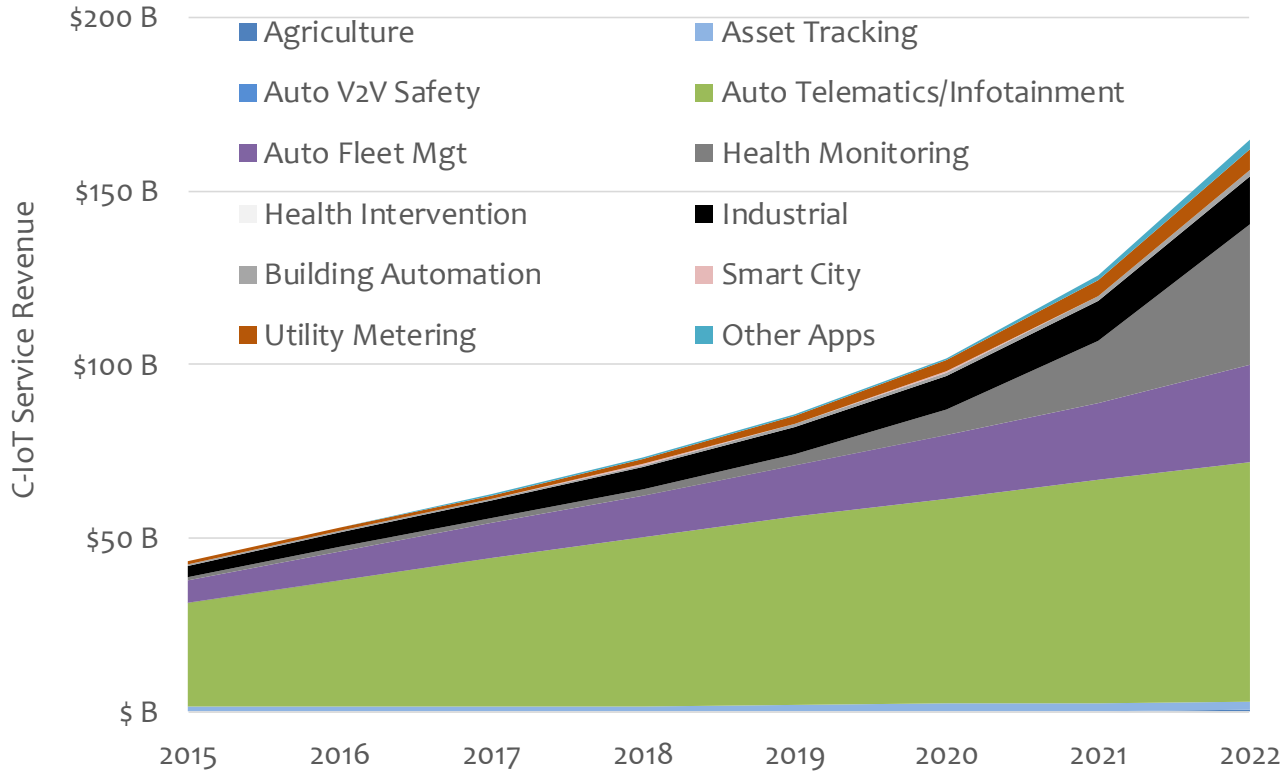

Chart 9: Cellular IoT Service Revenue, by application, 2015-2022

Source: Mobile Experts

DEVICE REVENUE

The device (including the C-IoT module or semiconductor components, plus sensors, memory, battery, antenna, etc) profile will vary widely between different applications. Device revenue and average prices will also differ widely between various use cases. Truly mobile applications will demand high-end LTE modules, and industrial devices will require ruggedization that simpler C-IoT modules (such as asset tracking devices) are not likely to use.

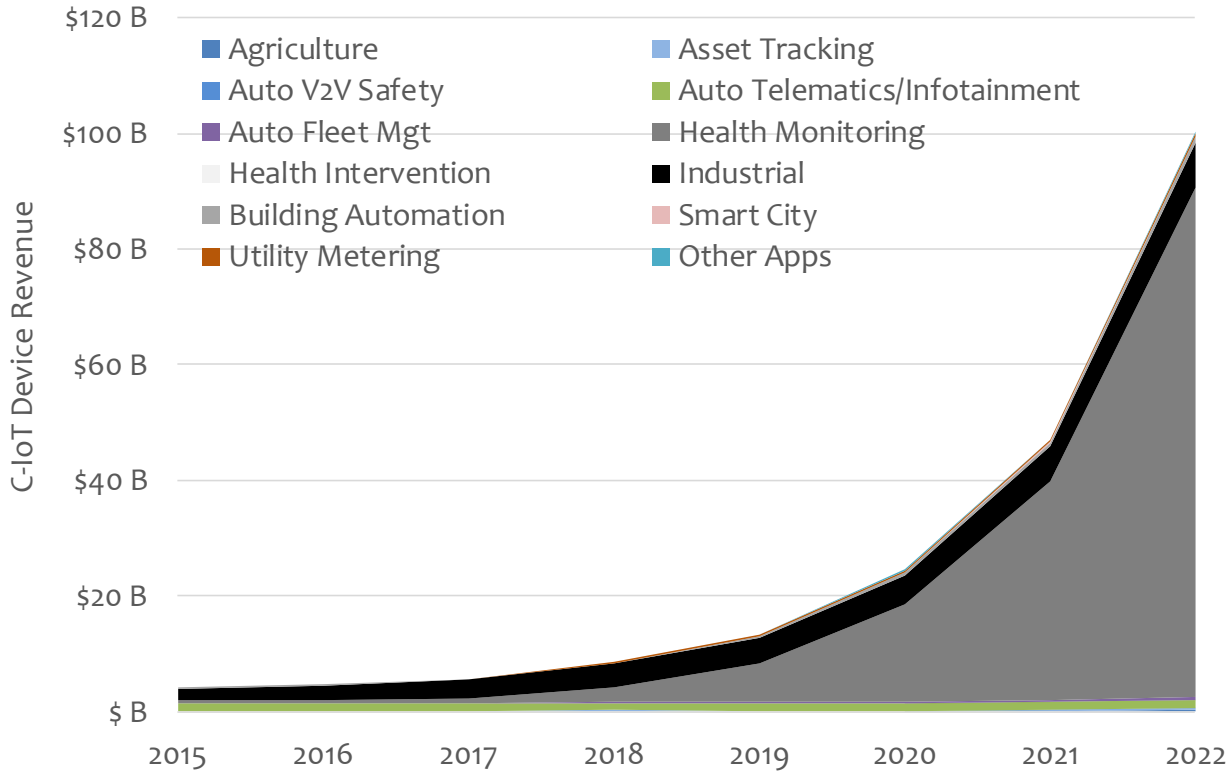

Chart 10: Cellular IoT Device Revenue, by application, 2015-2022

Source: Mobile Experts

CELLULAR IOT MODULE REVENUE

Cellular IoT modules that integrate the modem and RF components at a minimum will represent the majority of the market going forward. Companies that build the IoT devices are not interested in doing the integration work for the modem, transceiver, filters, LNAs, PAs, and other components… and in fact they often have very little RF expertise to be successful in that kind of integration.

GNSS is often integrated with the C-IoT module, but in our analysis we have excluded the GNSS function in terms of its impact on pricing and revenue. We have also excluded modules that are used for PC and hotspot applications (for coverage of the entire market including handsets, PCs, tablets, and IoT, refer to the Mobile Experts research on RF Front Ends for Mobile Devices)

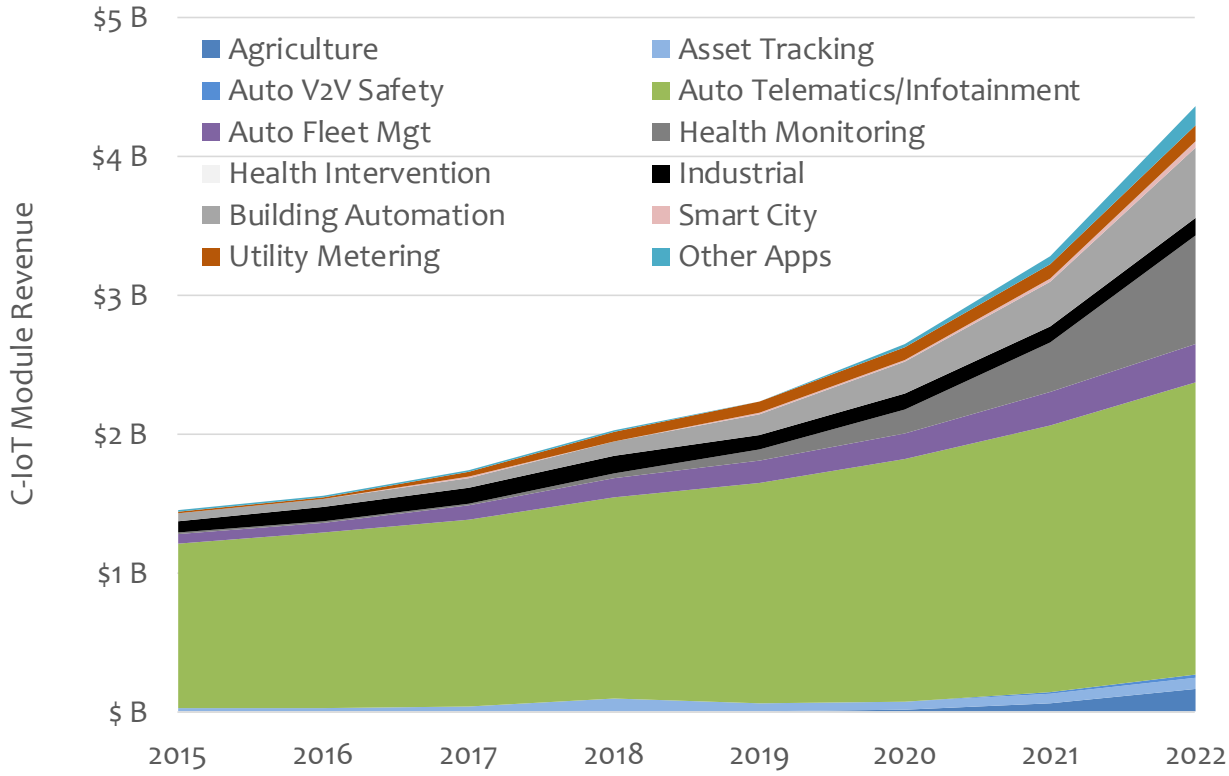

Chart 11: Cellular IoT Module Revenue, by application, 2015-2022

Source: Mobile Experts

As the technology shifts to LTE-M and NB-IoT, we expect increasing use of modules with high level economy of scale through key suppliers. Doing it yourself with discrete semiconductors will only be for big companies with huge volume.

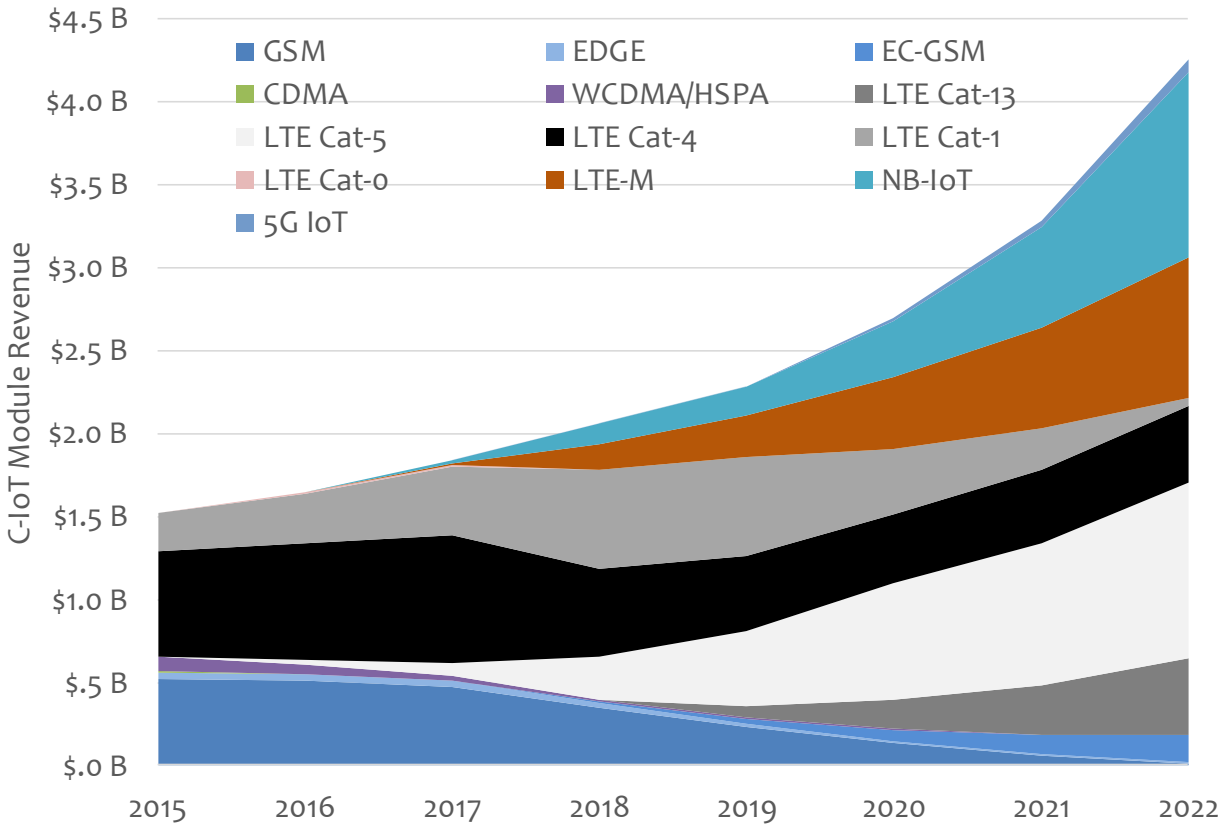

Chart 12: Cellular IoT Semiconductor Revenue, by technology standard, 2015-2022

Source: Mobile Experts

Sierra Wireless is the #1 supplier of IoT modules, with a strong position in automotive, asset tracking, and industrial applications, as well as substantial operations in North America, Europe, China, Japan, and other countries in Asia. Gemalto has solid revenue share with a strong European presence (as the former Siemens M2M business) related to automotive, heathcare, asset tracking, and smart meter markets. Telit gets roughly 75% of its revenue from the Americas and Europe, with a focus on industrial, enterprise, and automotive applications.

Quectel is growing extremely quickly, shipping 16 million modules in 2016 but double that number in 2017, and even more than double in revenue. U-Blox is strong in the European market with 60% of revenue in industrial areas and 30% in automotive. U-blox leads the market for positioning modules as well (these are excluded from our revenue and share estimates). SIMCom is a low-cost player in China that struggles to make money but came up with about $95M in revenue in 2016 by shipping millions of units at a loss. (Also, SIMCom shipped millions of fixed-wireless access modules in a Chinese program over the past 15 years but we don't count those in their IoT figures). WNC is small but has a strong position in the Americas and some Asian countries.

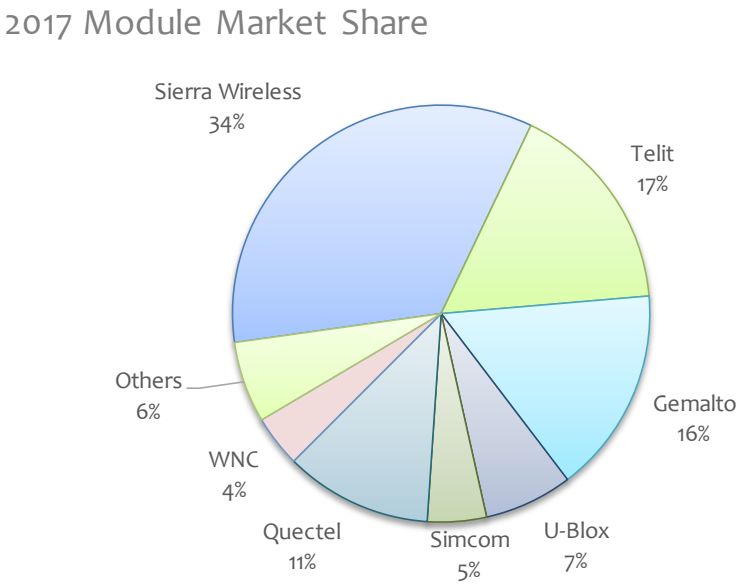

Chart 13: Cellular IoT Module Market Shares, 2017

Source: Mobile Experts. Note: Not including GNSS, or PC/hotspot modules….IoT only

SEMICONDUCTOR REVENUE

LTE semiconductor costs will come down quickly as suppliers like HiSilicon are pushing strongly on cot reduction for NB-IoT devices. We expect that as different applications jump on board with standard LTE-M and NB-IoT chipsets we will see the cost come down dramatically. Another aspect of the low-end C-IoT devices will involve the integration of modems, transceivers, and RF amplifiers on a single-chip CMOS platform, eliminating the higher cost associated with multiple discrete components.

Offsetting this trend is the push toward higher functionality. Automotive applications are using Carrier Aggregation with multiple bands and high level modems for high-speed Internet browsing in the car and download of large software updates.

In total, we expect pricing to drop quickly for many IoT semiconductors, which means that market growth will not result in such high revenue growth for chip vendors in the 2018-2020 time period. However, when NB-IoT volume grows to be significant we will see acceleration in the semiconductor sector.

Note that 5G IoT will not be significant in the next five years.

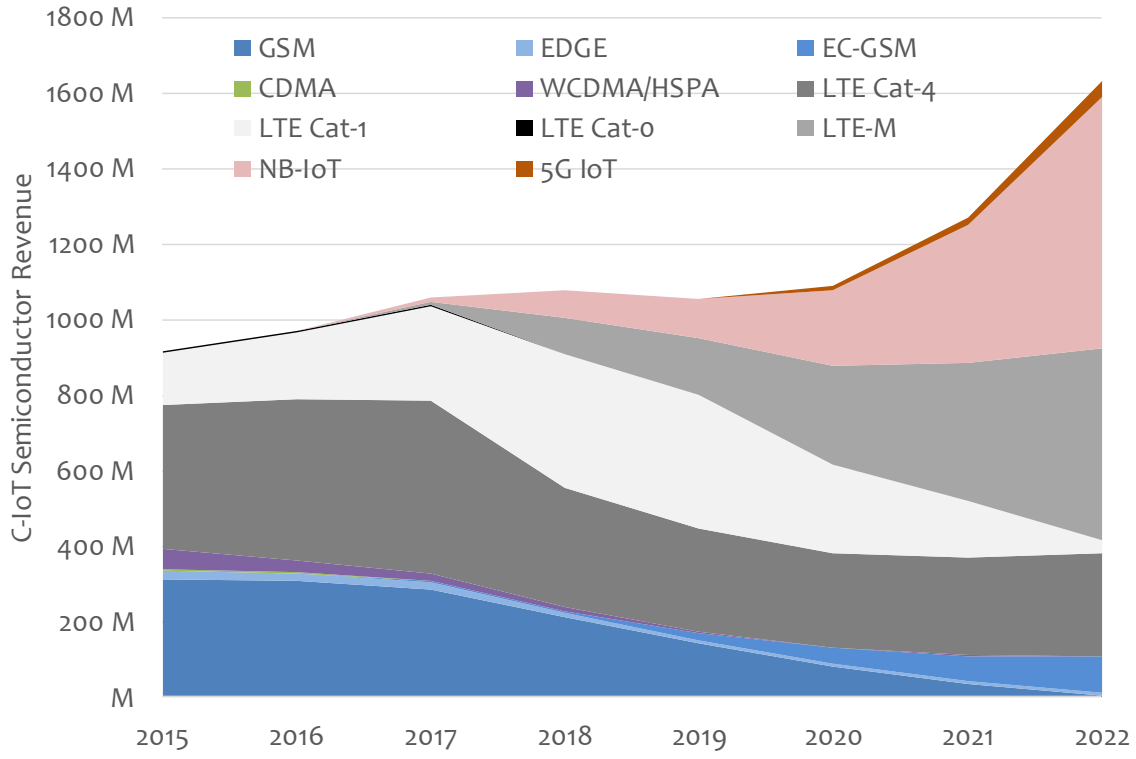

Chart 14: Cellular IoT Semiconductor Revenue, by technology standard, 2015-2022

Source: Mobile Experts

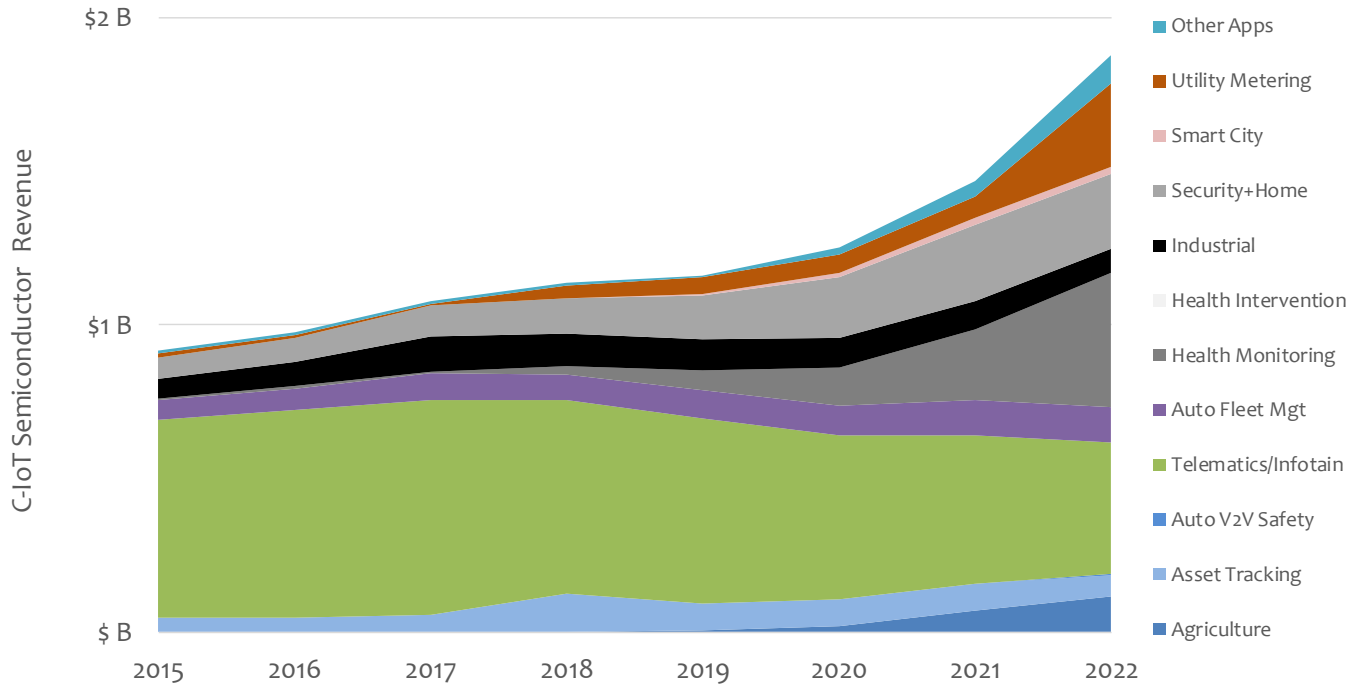

Chart 15: Cellular IoT Semiconductor Revenue, by application, 2015-2022

Source: Mobile Experts

In the case of semiconductors for C-IoT applications, we will not see the high levels of integration that are common in Bluetooth, 802.15.4, and other short-range wireless. Because the power amplifiers for C-IoT devices will transmit at much higher than +20 dBm, in general bulk CMOS power amplifiers will not be adequate, so discrete amplifiers will be used. In addition, the transceiver and modem will be separate devices for the next few years due to the different cadences of modem design and transceiver design. At some point in the future, Mobile Experts may track the integration of modems and transceivers, as LTE-M and NB-IoT move into the mainstream and settle into lower cost designs.

For now, we have chosen to simply track the use of multi-band RF designs and the RF semiconductor content associated with a second or third frequency band. In particular, telematics/infotainment applications are already driving Carrier Aggregation in the car, which adds significant additional RF content when two operating bands are in the same spectrum range (such as Band 2 and Band 4).

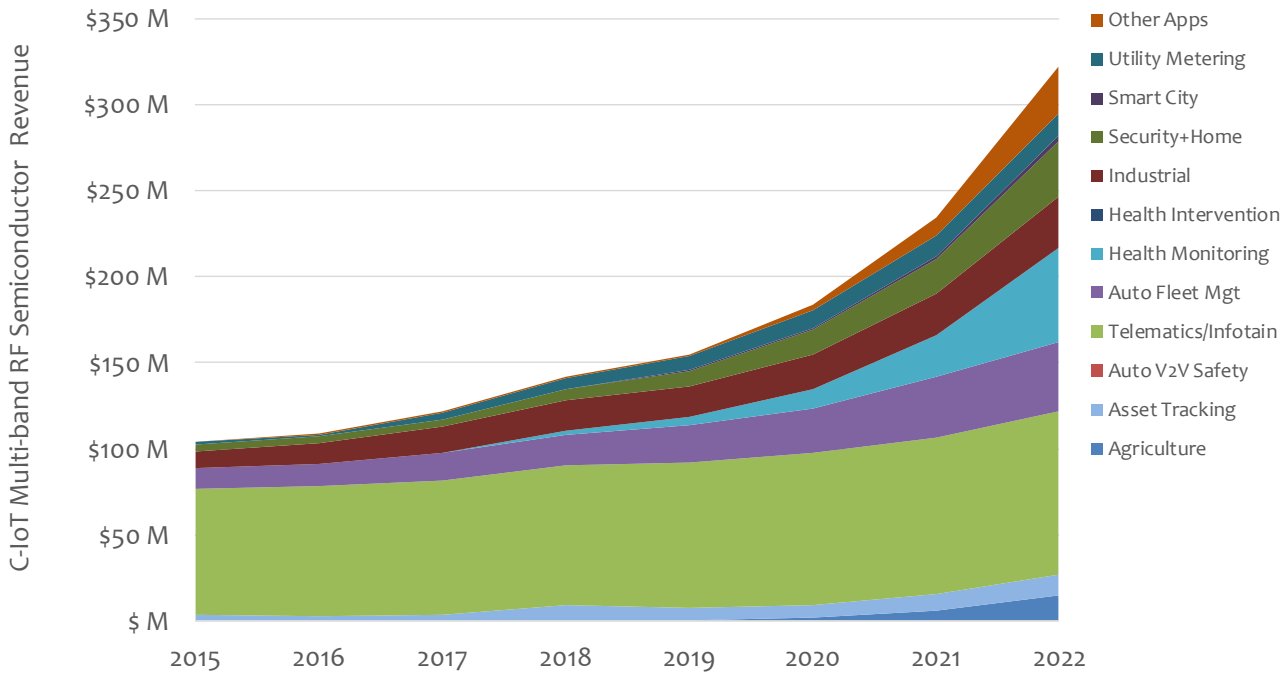

Chart 16: Cellular IoT Multi-band RF Semiconductor Revenue, by app, 2015-2022

Source: Mobile Experts

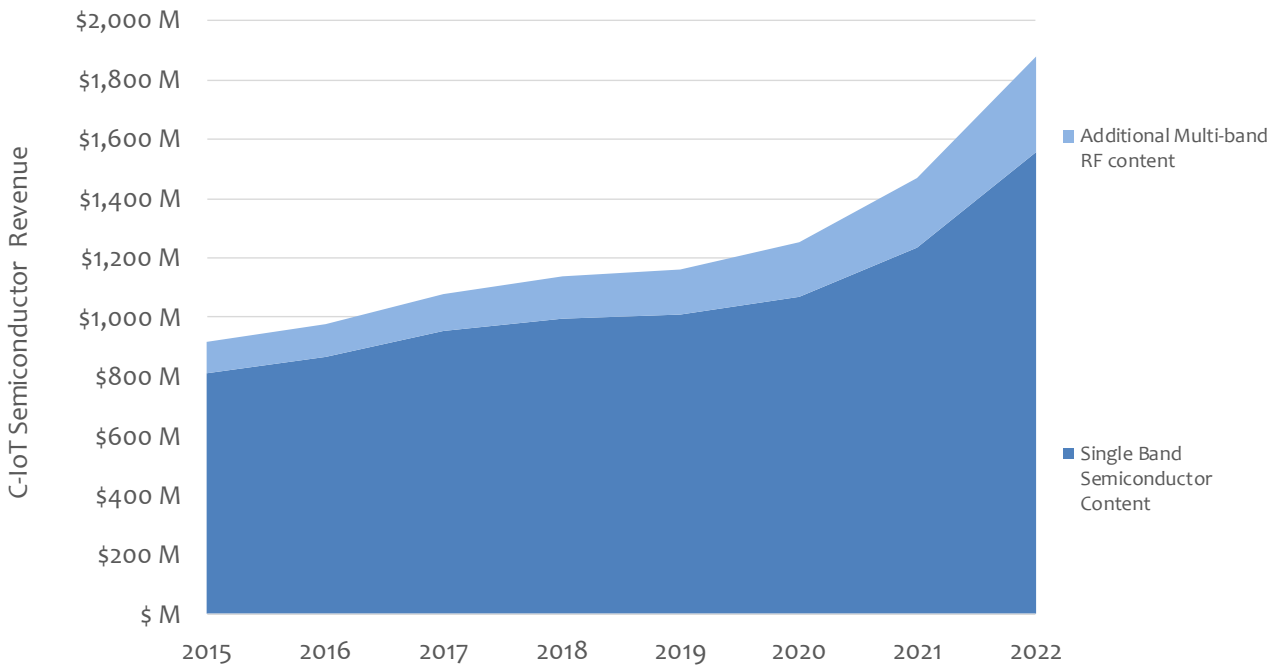

Chart 17: Cellular IoT Multi-band RF Semiconductor Revenue, totals, 2015-2022

Source: Mobile Experts

In the C-IoT semiconductor market, Qualcomm has a leading position because of its leadership in coming up with new modules quickly. Almost everybody works with Qualcomm to some degree and as a result they have opportunities with all of the module suppliers. HiSilicon is coming on strong with NB-IoT chipsets at low cost, but this has not made an impact on market share yet. Intel, Mediatek, and Spreadtrum naturally play in the C-IoT market with variations of modems developed in the handset market. Sequans and Altair come in with more optimized solutions.

Module Supplier	Chipset Vendors
Sierra Wireless	Qualcomm, Intel, Mediatek, Altair
Telit	Qualcomm, Altair
Gemalto	Qualcomm, Sequans
U-Blox	Qualcomm, internal
Simcom	Qualcomm for 3G/LTE, Mediatek for GPRS
Quectel	Qualcomm
WNC	Qualcomm, Sequans, Altair
ZTE Welink	Qualcomm

Figure 19 Chipset suppliers used by major Cellular IoT module vendors

Source: Mobile Experts

Note that the C-IoT semiconductor market includes the semiconductors sold to module OEMs, as well as semiconductors sold for discrete C-IoT devices. Most of the cellular IoT devices on the market use modules now, but discrete devices are still used for extra band support, for some high-volume applications that are customized, and for other customization of performance.

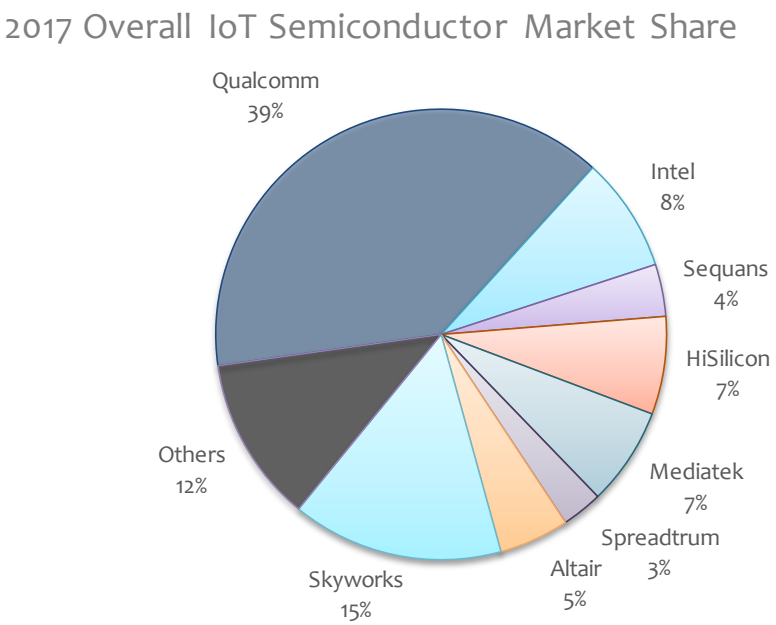

Chart 18: Cellular IoT Semiconductor Market Shares, 2017

Source: Mobile Experts. Not including PC/hotspots, GNSS. Including chips for modules and discrete IoT devices.

7 KEY COMPANIES AND MARKET SHARES

In the C-IoT market, of course mobile network operators are the key link in the customer chain, because they make the technical decisions about features and products. With over 500 mobile operators worldwide, we could present a very long list. Instead, we have listed some of the operators that take a leading role in developing and commercializing IoT applications:

MOBILE OPERATORS

AT&T
China Mobile
Deutsche Telekom
NTT DoCoMo
Orange
Softbank
Telefonica
Verizon Wireless
Vodafone

In addition to the operators, of course the OEMs and service providers that offer some kind of services to enterprise customers are clearly important. These are different in every field, with automotive OEMs, smart meter suppliers, and many other companies with specialized products in very different fields. These companies generally are not connectivity experts… they use module suppliers to insert the C-IoT function into their product.

MODULE SUPPLIERS:

DIGI INTERNATIONAL:

Digi supplies IoT devices in multiple industrial automation markets with well established customers and revenue in the range of $180M per year. The company has shipped more than 100 million IoT devices over the past 25+ years, mostly using unlicensed technology. The company provides both gateway and IoT device for enterprise customers. Applications range from intelligent transportation systems to smart meters, temperature sensors, and grid management.

GEMALTO

Gemalto is a well established IoT module supplier, but also derives a large percentage of its revenue from SIM solutions, secure software, and payment/banking solutions. The IoT module business represents only about 12% of total revenue, but it's important to Gemalto as the IoT device hardware opens up opportunities for software and security solutions. The company's strengths lie in European automotive, asset tracking, healthcare, and smart meter markets.

HUAWEI

Huawei has started investing heavily in platforms and solutions for IoT modules. Of course, Huawei's HiSilicon subsidiary develops chipsets. In addition, the company has developed the LiteOS operating system as an open-source platform for IoT developers, most of which are based in China. The company's market share is low today but we expect that Chinese app development in NB-IoT will begin to drive strong market share for Huawei over the longer term.

NEOWAY

Neoway is based in Shenzen, and supplies IoT modules ranging from simple GPRS modules to LTE, including NB-IoT modules for specific applications. The company has not been very visible outside of China but is active recently with several specialized NB-IoT applications.

NOVATEL (INSEEGO)

Novatel Wireless established a holding company called Inseego Corporation in November 2016 to re-brand itself as a pure-play IoT services company. Inseego is the holding company for multiple brands, including Novatel Wireless (responsible for IoT modules and gateways), Ctrack, MiFi, Skyus, and DMS. Novatel provides IoT modules for telematics, asset tracking, broadband, industrial, and security/surveillance applications.

QUECTEL

Quectel has enjoyed surprising growth over the last year, with rapid deployment of new IoT modules based on Qualcomm LTE-M and NB-IoT chipsets as well as existing LTE configurations. The company doubled its shipments to more than 32 million in 2017, mostly in Cat-1 and Cat-4 applications. Recent work in LTE-M and NB-IoT position Quectel well for the upcoming ramp in these areas as well.

SIERRA WIRELESS

Sierra Wireless is the clear leader in the IoT module area, with a strong position in the automotive, industrial, healthcare, mobile payment, asset tracking, smart meter, and other key markets and roughly 33% market share for modules. Sierra is focused on the module business but also focuses on cloud/connectivity services. The company recently acquired Numerex as one way to position itself for growth into the cloud services market.

SIMCOM

SIMCom has shipped a lot of wireless modules for local connectivity (Chinese wireless local loop) which we do not count as IoT devices. Discounting these, SIMCom is not as strong as they appear. During the past year, U-Blox attempted to acquire SIMCom and estimated that the company would add $75M of revenue to the U-Blox revenue stream. The acquisition came apart for unknown reasons… and SIMCom continues, with some success in penetrating AT&T, KDDI, China Mobile, and other key operator customers.

TELIT

Telit is a strong player in the C-IoT module market with revenue growth at least as strong as the market average in 2017. Telit provided about $290M of C-IoT modules in 2017 plus another $100M in IoT services and GNSS devices. Telit acquired GainSpan during 2017, adding more depth to Wi-Fi and other low power IoT solutions… but its main thrust remains in higher-value Cellular IoT modules and the cloud services that they lead to. Telit recently has also introduced a LoRa product to offer a more complete LPWA portfolio.

U-BLOX

After its failed acquisition attempt on SIMCom, U-blox has continued to develop its IoT modules and GNSS positioning devices. U-Blox is the leader in GNSS modules and many of its IoT modules take advantage of that strength, with many integrated devices as well. U-Blox is a solid player in the automotive IoT area, and has products now ranging from GSM through NB-IoT as well as RPMA.

WNC (WISTRON NEWEB)

Based in Taiwan, WNC supplies automotive, industrial, smart home, and asset tracking modules with low-cost products that lag somewhat behind the leading module suppliers but have been approved by major operators such as Verizon and AT&T. By focusing on specific markets such as the US industrial and automotive sector WNC has established a niche for itself.

ZTE

ZTE Welink is a subsidiary of ZTE which focuses on cellular IoT modules, with key relationships at operators such as AT&T, DoCoMo, SK Telecom, T-Mobile , and Verizon. Using Qualcomm modem chipsets and a rapid-reaction engineering team, ZTE has the ability to introduce some features quickly and get the attention of auto manufacturers and industrial operations in the Chinese market.

SEMICONDUCTOR SUPPLIERS:

Of course, the modules would not exist without semiconductors. 60-80% of the module's cost can be traced back to the semiconductor devices that do the work: modems, transceivers, power amplifiers, filters, power supply devices, and other chips are key.

Key semiconductor vendors include:

ALTAIR SEMICONDUCTOR (SONY)

Altair was acquired by Sony during 2016, but the acquisition has not affected this small company's ability to address the module market. Altair specializes in pushing the envelope for low power and small size solutions in proprietary SoCs with minimal external components. Altair integrates baseband processor, RFIC, PMU, memory, as well as GNSS and RF functions onto a single chip to lead in small size and component count.

ARM

Of course, ARM is well known for the processor cores that take care of the computing requirements in most mobile devices. ARM is ever-present in the IoT market, as low power computing cores are required in the IoT market as much as in smartphones.

BROADCOM

Broadcom provides basic RF components for mobile handset applications, so naturally many of the Broadcom filters, power amplifiers, and other devices. Broadcom is not as focused in this area as Skyworks and therefore has not achieved as many top-tier design wins for components with customized performance features. Note that Broadcom, upon merging with Avago, divested its IoT business to Cypress Semiconductor.

GCT SEMICONDCUTOR

GCT Semiconductor has launched a common single-chip solution for Cat-M and NB-IoT applications. GCT integrates RF transceiver, baseband, and memory functions but has not pursued the integration quite as far as Altair to maintain some flexibility. Based in Korea and California, GCT has some relationships with Asian module vendors but is generally seen as a

low cost chipset vendor. GCT has also introduced an interesting dual-mode C-IoT/Sigfox solution which may find interest in specialty markets.

HiSilicon (Huawei)

Huawei's level of investment in IoT has grown dramatically based on pressure from the Chinese government to develop NB-IoT networks nationwide. HiSilicon, as Huawei's in-house chipset supplier, has a very rapid turnaround time for new SoC development and has chosen to use its rapid development cycle to develop separate LTE-M and NB-IoT chipset products. Mobile Experts anticipates that this decision could lead to much higher market share for HiSilicon in NB-IoT, as they are likely to achieve lower cost than competing SoC vendors with common LTE-M/NB-IoT products.

Intel

Intel remains in the modem market for handsets and also provides LTE modems for IoT applications. So far we have not seen Intel push into the lead with any performance attributes or time-to-market features in the IoT modem area… but Intel has an advantage when it comes to applications for mobile edge computing. In areas such as Smart Cities where on-board computing platforms using the X86 architecture would be helpful, Intel can step into a role of providing connectivity and computing platforms together. Time will tell as to whether the company can successfully put together a strategy to take advantage of this kind of synergy.

Qorvo

Qorvo is a leading RF component supplier and has a strong business for discrete devices in the RF front end of an IoT module. Between Qorvo, Broadcom, and Skyworks, the level of technology differentiation in IoT applications appears to be pretty low, so the competition for filters, power amplifiers, switches, and other RF front end devices will be more based on sales channels and focus on the IoT market than on technology. Qorvo will benefit as the market turns toward Carrier Aggregation and multi-band RF solutions.

Qualcomm

Qualcomm is the clear, undisputed champion of the Cellular IoT market so far. Because Qualcomm introduces new modem chipsets earlier than other vendors, almost every module supplier uses Qualcomm's reference design as a starting point… and some move on to work with other chipset suppliers in order to maintain a balanced portfolio. Qualcomm has also invested heavily in the RF front end, so they're the only company on our list that participates in both modem and RF markets.

Qualcomm also has invested heavily in developing software and cloud applications in key IoT vertical markets such as healthcare, smart cities, and other areas.

Note that Broadcom has initiated a hostile takeover attempt to buy Qualcomm, but we don't expect this initiative to succeed.

SEQUANS

Sequans is a solid, growing supplier of IoT modems and is one of the few companies that is very focused in this area. Sequans has been able to develop some IoT solutions very quickly because of their focus on the IoT market, so for example they were first to market with a common Cat-M/NB-IoT modem. The company is growing rapidly at about 40% CAGR between 2014-2016, although 2017 is likely to come out at somewhat lower growth (about 10%).

MEDIATEK

Mediatek has been quite successful in the handset market over the past 8 years, taking significant share away from Qualcomm in the smartphone market where Chinese OEMs were looking for a local supplier. So far, Mediatek has been distracted by this growth and has not been as successful with design wins for IoT modules… but that may change as Mediatek has released NB-ioT modem products including one stand-alone NB-IoT modem and a second product with dual-mode GSM/NB-IoT operation.

SKYWORKS

Skyworks has been very focused on the IoT market and targeted early design wins with bellwether products such as Amazon's Alexa, Nest thermostats, and Fitbit smart watches. The company derives about a billion dollars (one third) of its revenue from non-handset applications, and we believe that roughly one third of that is actually IoT related. Only half of its IoT revenue is Cellular IoT related, as a lot of the high-profile platforms Skyworks has focused on are based on Wi-Fi.

SPREADTRUM

As a handset modem supplier, Spreadtrum has basic connectivity for LTE and offers a line of modems which can be adapted readily for IoT applications. We have not seen the kind of focused IoT strategy that Qualcomm, Altair, Sequans, and other companies have shown so we expect Spreadtrum to follow behind the market leaders with a low-cost modem product.

8 ACRONYMS

2G: Second Generation Cellular
3G: Third Generation Cellular
3GPP: Third Generation Partnership Project
4G: Fourth Generation Cellular
5G: Fifth Generation Cellular. Mobile Experts uses "5G" to refer to devices using a New Radio waveform
802.11: The IEEE working group for unlicensed local-area networks
802.11a: IEEE standard for broadband networking with 20 MHz channels
802.11ax: IEEE standard for broadband newtworking, up to 160 MHz channels
802.11p: Variation of IEEE standard for vehicle-to-everything communications
802.15.4: An IEEE standard which specifies PHY and MAC for low datarate personal area networks
AES-128: Advanced Encryption Standard-128 bit
ARPD: Average Revenue Per Device
ASK: Amplitude Shift Key modulation
ASP: Average Selling Price
BLE: Bluetooth Low Energy
Bps: bits per second
BLE: Bluetooth Low Energy (Bluetooth 4.0+)
BT: Bluetooth
C-IoT: Cellular Internet of Things
Cat-13: LTE Category 13. In this report "Cat-13" devices refer to the uplink standard.
Cat-5: LTE Category 5 In this report "Cat-5" devices refer to the uplink standard.
Cat-4: LTE Category 4
Cat-1: LTE Category 1
Cat-0: LTE Category 0
Cat-M: LTE Cat-m1, also known as LTE-M
Cat-m1: LTE Category m1, commonly called LTE-M
Cat-m2: NB-IoT as referenced in 3GPP
Cat-NB1: The NB-IoT or Narrowband Internet of Things standard as referenced in 3GPP
CDMA: Code Division Multiple Access
dBm: A measurement of radio signal strength
EC-GSM: Extended Coverage GSM
FCC: Federal Communications Commission (USA)
FSK: Frequency Shift Key modulation
GFSK: Gaussian Frequency Shift Keying modulation
GHz: Gigahertz
GM: General Motors
GMSK: Gaussian Minimum Shift Keying modulation
GPRS: General Packet Radio Service
GPS: Global Positioning System
GSM: Global System for Mobile (2G cellular standard)

Hz: Hertz
IoT: Internet of Things
IPv6: Internet Protocol version 6
ISM: Instrumentation, Scientific, and Medical (a designation for unlicensed spectrum)
J3016: SAE International standard for automated driving reference
Kbps: kilobits per second
kHz: Kilohertz
LAN: Local Area Network
LNA: Low Noise Amplifier
LoRa: Long Range (a low power, wide area wireless format)
LPWA: Low Power Wide Area communciations
LTE: Long Term Evolution (a 4th generation cellular standard)
LTE-M: LTE Category-M1 standard (for machine communications)
LTE-V: LTE adapted for vehicles
M2M: Machine-to-machine communications
Mbps: Megabits per second
MCU: Microcontroller Unit
MHz: Megahertz
mW: milliwatts of power
NB-IoT: Narrowband IoT (a 3GPP based wireless standard)
OBU: On Board Unit
OFDM: Orthogonal frequency division multiplexing
PA: Power Amplifier
PHY: Physical layer of a system
PLC: Power Line Communications
QAM: Quadrature Amplitude Modulation
RSU: Road Side Unit
UNII-4: Unlicensed National Information Infrastructure, 4th band
V2I: Vehicle to Infrastructure
V2V: Vehicle to Vehicle
V2X: Vehicle-to-everything
W-CDMA: Wideband Code Domain Multiple Access, a 3G radio interface
WAN: Wide Area Network
Wi-Fi: Wireless Fidelity (refers to the broad family of 802.11 standards)

9 METHODOLOGY

Mobile Experts investigates the IoT market in two distinct ways, in order to compare the results and create the most accurate forecast possible.

1. First, Mobile Experts investigates the market according to vertical market segments. We publish a series of market study documents on eight vertical markets throughout the year:
    a. Utility Meters
    b. Healthcare and Fitness Devices
    c. Automotive IoT
    d. Asset Tracking
    e. Industrial IoT
    f. Smart Cities
    g. Agriculture
    h. Security/Building Automation
2. We also investigate the number of devices used in each technology area. For example, in the automotive market, we have interviewed Ford, GM, Honda, Toyota, Mitsubishi, Kia, Daimler, and BMW in order to chart the use of various LTE modes in the automotive sector. We interviewed a similar list of OEMs in the smart meter market. We check the OEM inputs in our interviews with direct input from semiconductor and module vendors, to verify that the two data sources agree with each other. We routinely interview about 15-20 IoT semiconductor suppliers related to various markets in order to verify pricing, market shares, and shipment numbers.

Mobile Experts estimated the pricing and revenue of C-IoT modules by technology (Cat-4, Cat-1, LTE-M, etc) and then separately estimated pricing/revenue by application (automotive, healthcare, industrial, etc). We adjusted our module pricing assumptions until these two estimates matched within 5%. In this way, we arrived at average market prices instead of using only the anecdotal data obtained from suppliers.

Overall, Mobile Experts compares the technology-based forecast with the vertical market forecast, in order to validate each approach. When these two methods do not match, we do more direct investigation with suppliers in the industry to determine why they are different.